A STUDY OF THE OCEANS

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SECOND EDITION

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PREFACE TO THE FIRST EDITION

Our present knowledge of the physical geography of the ocean—that is, the modern science of oceanography—is only about one century old. During this period most of the great voyages of exploration that had physical and biological objects, rather than purely geographical ones, have been made.

Nevertheless the old voyagers—even those of classical times—did really investigate the physics and biology of the ocean although they were mainly concerned with finding out what were the routes, across sea, between different parts of the earth. It is of great interest to trace the growth of our knowledge of the world ocean from remote periods, and the stories of these maritime explorations have an extraordinary fascination for most people. The records of adventure; of the penetration and discovery of unknown regions where almost anything might have existed; of disaster and tragedy and heroism—all this confers on the history of the old voyages a very great attractiveness. And then the expeditions that have led to the discovery of the forms and dimensions of the oceans were not made merely with the object of adding to geographical knowledge, because we can nearly always trace some real or ostensible economic or political aim. The results that have been attained have had notable consequences with regard to the balance of political power, and this aspect of our subject is one that also has remarkable interest.

Thus a study of the growth of oceanographical science has various aspects. One does not usually find all of them dealt with in modern text-books, and this is regrettable, for they are very interesting. Prince Henry the Navigator established a slave trade; the great Portuguese voyages from 1511 onwards were financed by the bankers of Rome, Florence, Lombardy and Germany; the practical discovery and application of the monsoons in the Arabian Sea were made by Roman sailors during the first century of the Empire and were used to avoid interference by Arab traders; the *Challenger*

voyage of the nineteenth century led to the discovery and exploration of very lucrative phosphate deposits, as well as that of new trawling grounds; the circumnavigation of the world by Magellan led to a great controversy about the sovereignty of the high seas that has lasted until our own days—these are instances of the interesting ways in which scientific geography has become mixed up with economic and political affairs, and it is good for the student to have all these aspects of the subject presented to him.

Nowadays we begin our study of geographical science with some notion of the structure of the earth and of its relation to other cosmic bodies: thus we cannot begin to read the history of our subject and appreciate properly its gradual development because we already know much more than, say, Copernicus, or Columbus, or Magellan. This cannot be helped and so the best thing to do is to have clear general ideas about the latest results of investigation. Therefore we begin this book with a short summary as to the ways in which the evolution of the main features of the face of the earth have probably come about. Then we go on to consider the slow growth of scientific geography from the time of the Greek natural philosophers down to the end of the medieval period. After that we deal with the results of modern oceanographic investigation in so far as it will help us in visualizing the rather dry and even repellent description of topographical earth-features—which, unfortunately, is what used to be called geography.

A short list of books dealing with our subject is given in the Appendix. This will help students who may wish to read further with respect to one or other of the subjects dealt with in this work.

J. J.

January, 1926.

PREFACE TO THE SECOND EDITION

The opportunity of reprinting has been taken in order to correct inaccuracies and misprints in the first edition of the book. Some of the statements appear also to require a little amplification and this has been done in the appendices, where sections have been inserted on Isostasy, Wegener's Hypothesis, Methods of Navigation, Additional records of voyages in the Circumpolar Regions, the Tides, and the climate and life of the ocean.

J. J.

February, 1930.

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A STUDY OF THE OCEANS

CHAPTER I

THE GEOLOGICAL HISTORY OF THE OCEAN

When we look at a map of the world or, still better, at a terrestrial globe, we see a certain, very familiar configuration of land and water. There are oceans, continents, seas, islands, straits, bays, mountain ranges, deserts, ice, etc., and all these superficial features of the face of the earth have an arrangement which we study in topographical and physical geography. Much of the succeeding chapters of this book deals with the study of the configuration of land and water and the gradual development of our present-day knowledge about it. In this chapter, however, we shall deal with the origin of these great earth features and with their evolution in geological time. It would be an unsatisfactory thing merely to describe them without enquiring how they have come into existence; that is, we cannot study physical geography with much advantage unless we also pay some attention to cosmogony. Here we can only treat this vast subject in a very general way and give the student some general ideas as to a branch of science that is making very rapid progress at the present time.

The Origin of the Earth

First, then, we enquire into the mode of origin of our planet itself because on the hypothesis that we adopt will depend our answers to the question as to how the present configuration of land and water came into existence. Until near the end of the nineteenth century the well-known nebular hypothesis was regarded as giving us an explanation of the formation of the solar system. It was known that the sun was very hot, and liquid or gaseous; that the planets and their satellites revolved round the sun, and nearly all

rotated on their own axes in the same direction. Further the extraordinary rings of the planet Saturn seemed to suggest how the whole solar system came into existence. It was supposed that the materials of the sun, planets and satellites once existed in a vast nebula, or mass of vapour, extending out beyond the orbit of Neptune. This nebula was very hot and it was in slow rotation. It tended to condense towards its centre because of the mutual gravitation of its molecules and as it so condensed it would become hotter and smaller and denser. As it became smaller and denser it was bound to rotate more rapidly, and this process of condensation, with increasing rotational velocity, went on until a certain limit was attained. At this limit the centrifugal force became equal to the gravitative (or centripetal) force and when the limit was passed parts of the condensing nebula became thrown off into space and these parts cohered together, each of them forming a planet. In much the same way the satellites were formed from the planets.

Now, during the nineteenth century our knowledge of the masses, distances and motions of the various bodies of the solar system became very detailed and powers of mathematical-physical investigation were highly developed. Therefore it became obvious to astronomers that, if the bodies of the solar system originated in the way suggested, these bodies should display certain masses and motions and not *any* kinds of masses and motions. But this theoretical behaviour could not be observed. Further it became possible for the mathematicians to deduce what would happen in a large, hot, rotating nebula, and by no means could the origin of planets by centrifugal force be adequately explained. Therefore, well before the end of the nineteenth century, the nebular hypothesis had to be abandoned.

The Tidal Hypotheses. It was suggested by various scientists that two stars might be travelling in the same straight line and towards each other so that they might collide. Even if they were both cold and solid the heat generated by the friction of the impact would be so enormous that all the materials of the colliding bodies would be volatilized so that an incandescent nebula would come into existence. But even if this were so there would still be the same difficulty in accounting for the formation of a large, central sun surrounded by a number of small planets. Further, astronomers knew a great deal about the distances apart and the proper motions of the stars, and it was easy to calculate that the proba-

bility, in the mathematical sense, of a direct, head-on collision between two cosmic bodies was incredibly small. Now the chance of two stellar bodies *approaching* each other was very much greater, so great that it seemed quite proper to regard such an approach as a competent cause of formation of a planetary system. Further, the large number of the very peculiar spiral nebulæ in the sky suggested that some such process had occurred very often in the past.

The Planetesimal Hypothesis. After a good deal of investigation (notably by Sir George Darwin) an hypothesis of origin was devised by Chamberlin. Consider an ordinary marine tide. The moon is near enough to the earth to exercise a very considerable attractive force. Because of their respective motions in their orbits the moon and earth are not pulled together by this attractive force but remain always at the same mean distance apart. But the force of the moon's attraction would be great enough to pull the earth out of shape if the latter were not so strong as to resist the tendency to deformation. The water of the ocean, however, is not strong in this respect and it yields to the attractive force of the moon (and sun, of course) and so tides are formed. Tides are heapings-up of the water of the ocean due to the condition that the moon's gravitative force can deform the mobile ocean while it cannot deform the earth (which is as strong as if it were made of tempered steel). But if the earth material were much less strong it would yield and tides in its solid substance would actually be formed.

Now let us go back (some thousands of millions of years) to a time when the solar system, as such, did not exist. There was only our sun, in the form of a star and containing in itself all the materials of the planets. It was very hot and gaseous. Let us imagine another star of much the same mass to approach it—that is, to come near enough to set up strong tides in the solar body. That might be all that would happen, but let the strange star come nearer still and the solar tides would become so violent that the sun's body would be ruptured. Huge masses of gaseous material would be ejected, or belched out, with such velocities that they would not fall back again on the sun but would continue to revolve round it.

What would then happen to these ejected masses of solar material? Chamberlin thought that, being very hot and gaseous, they would expand enormously and then cool so rapidly that great clouds of cold and solid dust would result. Probably the planetesimal dust would be more aggregated at one place and so this would

become the nucleus of a planet. By and by it would attract the remainder of the dust and so a planet would gradually *grow*. If the strange star, in its passage round the sun, caused a number of solar eruptions, in this way we should have our solar system.

The new Tidal Hypotheses. Now attractive and plausible as it was the planetesimal hypothesis did not withstand searching criticism on the physico-mathematical side. Jeans and Jeffreys have shown that as the stranger star swung round our sun the tidal effects would follow with the result that a number of huge streamers of hot gaseous material would be pulled out. A certain part of each streamer would form a kind of atmosphere round a mass of incandescent gas, revolving about the sun. In time each of these masses would become globular, gaseous planets. Whereas, on the planetesimal hypothesis, each planet was small at first but gradually increased in mass by attracting to itself the planetesimal dust, on the newer hypothesis each planet would be about as big at first as it would be at any later stage. Whereas the planets formed from the cold dust would at first be at a low temperature, those formed according to the new hypothesis would at first be intensely hot.

Now this is what we want, in order to account satisfactorily for the later evolution of the earth. We must have a planet originally gaseous, then molten, and cooling all the time, but so slowly that it is still intensely hot inside. We know that as we go down deeper and deeper into the crust of the earth the temperature continues to rise: therefore the earth is hot inside. But on the planetesimal hypothesis it is only locally hot.

We conclude, then, as the best and most helpful hypothesis that we have, that the earth and the other planets were formed, from the sun, by a process of disruption set up because of the near approach of another star. This caused violent tides in the solar body and strained the latter so enormously that fragments were ejected. Each fragment formed a planet. Each planet was originally intensely hot and gaseous. Then it cooled and became cold on the outside.

The Age of the Earth. It will, perhaps, be sufficient merely to say just now that all this occurred several thousands of millions of years ago.

The subsequent History of the Earth. Beginning, then, as a globular mass of gas at a temperature of 1,000° C. to 2,000° C. the earth would radiate its heat away and begin to cool down. At first parts of its

external substance would pass into the forms of liquid drops which would tend to sink down towards the centre. They would then heat up again and volatilize, but in doing so they would withdraw heat from the deep layer of gas. This would go on again and again until the entire earth would become liquid—but still intensely hot, of course. Next the rapidly cooling superficial layer would become solid and this solid crust would break up and its fragments would tend to sink down into the lighter liquid mass (a surface skin would *not* form, like ice forms on water, because ice is lighter than water, whereas solid rock is heavier than liquid rock). As the fragments of solid crust sank down into the liquid earth they would re-melt, again accompanied by a withdrawal of heat from the internal fused mass, and this would go on again and again until the whole interior would become a kind of solid, honeycombed with cavities containing liquid. Finally a permanent solid crust would form on the surface of a quasi-solid interior. (Note that though the temperature might be high enough to melt rock, if the pressure were that of the atmosphere, the actual pressure is great enough to prevent the rock from melting.) Thus at a time of about 1,000 to 2,000 millions years ago this would be the result: the earth would be solid and fairly cool on the outside and for some little distance down. There would thus be a solid crust and beneath this a highly heated quasi-solid internal body.

The Age of the Earth's Crust. If we make certain allowable assumptions we arrive at the conclusion that the temperature of the earth, soon after it was formed by the rupture of the sun, was about 1,200° C. to about 1,400° C. Relatively soon afterwards (that is, after several tens of thousands of years) the process of cooling had proceeded so far that a permanent solid crust was formed. Knowing something about the original temperature and the rate of conduction of heat through the crust, we can calculate that at the centre of the earth the original temperature (between 1,200° and 1,400° Centigrade) still exists. At a depth of about 300 kilometres (186 miles) the cooling is only about 200° C. to 300° C.: that is, the temperature is about 1,000° C. At a depth of 700 kilometres (434 miles) there is no cooling, and the initial temperature (1,200 to 1,400° C.) still holds. At the surface the cooling is complete: that is, the temperature would be that of cosmic space (about −270° C.) if the earth were not heated by radiation from the sun.

How long ago is it since the first, cold, permanent crust formed?

An astronomical method gives us the result: it is more than 1,000 millions, and less than 10,000 millions of years since the materials of the earth broke away from the sun—this is the approximate age of the solar system. But the formation of the solid crust of the earth took place not so long ago as that and there is now a method for finding this period of time. Many rocks contain the elements uranium and lead. Uranium is now known to undergo radioactive disintegration, that is, its atoms actually break down into atoms of a simpler kind. Helium, radium and other radioactive substances are thus formed as the result of the disintegration of uranium, but the final product of this series of changes is the substance that we call lead—not ordinary lead, but an "isotope" of lead. So if we know (as we do know) the ratio of lead to uranium in many kinds of rock, and if we know (as we do know) the rate of transformation of uranium into lead, we can calculate the age of these rocks. The result is about 1,300,000,000 years. This is the best estimate of the age of the earth's crust and it is probable that it is a minimal estimate: the crust is, *at least*, as old as the period of years mentioned.

The History of the Earth's Crust

Thus about 1,000 to 10,000 millions of years ago our earth had its origin and soon afterwards the moon was formed from the gaseous earth.[1] The earth then was very much larger than it was when the solid crust became formed (that is, it contained also the materials of the moon, and it was greatly expanded because it had not condensed very much since its formation by rupture of the sun). It rotated round its own axis in a period of about four hours. The attractive force of the sun set up enormous tides in the gaseous substance of the earth and a condition of what is called "resonance" became established. The meaning of this is that the tides tended to become greater and greater, without limit, and so the time came when the earth became ruptured and the materials of the moon broke away from it. After this the earth settled down and began to assume the conditions that we have just described. When the solid crust had formed it was rotating on its axis faster than it does now, so that the length of the day was about twenty hours.

Future of the Earth-Moon System. For a moment we digress to

[1] The old notion, that the Pacific Ocean represents the "scar" left when the moon was formed, is quite erroneous.

consider the future of the moon. It can be shown that the tides on the *oceans of the earth set up friction; that is, they dissipate* energy. This energy that is so dissipated is the energy of rotation of the earth on its axis and that of the revolution of the moon round the earth, and so these motions must slow down. There will be a two-fold effect of this dissipation of energy due to earthly tides: (1) the length of the earth's day (that is, the period of rotation of the earth round its axis) will gradually increase and (2) the length of the month (that is, the period of the revolution of the moon round the earth) will also increase. Ultimately the length of the day and that of the month will be the same and will be equal to forty-seven of our present days. The period of time required for this is great—it will come about after 50,000 millions of years since the time when the moon was formed from the earth. This does not end the history of the earth-moon system: after the time when the length of the day and that of the month have become equal the moon will begin to approach the earth and ultimately it will come so near that the tides set up in its body by the attraction of the earth will then become very great. They will become so great that the materials of the moon will become disrupted and will form a system of small bodies (" lunitesimals ") revolving round the earth like the present rings of Saturn.

The continued Cooling of the Earth. Thus the originally large gaseous earth lost heat by radiation, condensed to the liquid form, becoming much smaller, and so formed a solid crust of rock on its surface. This crust, originally very hot, would continue to cool. At first it would become broken up again and again, but at last it would become permanent. Then it would cool down because it would lose heat by radiation into space much more rapidly than it would receive heat by conduction from the hot interior. It would assume a temperature very much like that which it has now while a few miles down the temperature would be over 1,000° C.

That being so the crust would suffer enormous tension strains as it cooled because everywhere it would be contracting. Just as a piece of hot glass will contract when it is rapidly cooled and so must crack violently, so the contracting earth crust would also crack. These cracks would cover the surface of the original crust, dividing up the latter into huge polygonal areas. Molten rock would rise up from the interior and fill up the cracks. At the central parts of the polygonal crust-areas bounded by the cracks there would be regions of

elevation and in the crack zones there would be regions of depression.

All the time the heated earth interior would be cooling as heat was being conducted away through the crust. So the above process of contraction and cracking would go on again and again until a relatively thick and strong crust would be formed. This might be anything from 10 to 100 miles in thickness. It would have become cool and it would have ceased to contract. But note how complex the conditions really are: for a certain depth the crust is cool and has ceased to contract, but if we go deep enough we shall come to a layer which is still at the original temperature, which remains nearly constant at that temperature and which is not contracting. Between these two layers of practically constant temperature—the upper one cold and the lower one very hot—there must be a layer which is cooling and contracting.

As this intermediate layer cools and contracts it shrinks away from the superficial layer—which has ceased to contract. Therefore the crust must, sometime in the past, have become too big for the shrinking interior, and since it is supported upon the latter it must give way, somehow or other. Now it was in connection with this giving way of the surface layers that the great earth features, regions of elevation and depression, came into existence.

The Origin of the Envelopes of the Earth

As soon as the crust became cool and permanent the envelopes would begin to form. There are two of these—the *hydrosphere,* or watery envelope, and the *atmosphere,* or gaseous one.

Origin of the Hydrosphere. Where did the water of the ocean come from? It is very difficult to answer this question on the planetesimal hypothesis because even if there were water, or the elements of water, in the material coming from the ruptured sun this water would not be held by the original earth. In order to retain volatile matter, like water vapour at a high temperature, or air, a cosmic body must have a certain gravitative force—that is, it must be of a certain minimum size. Thus the moon is not big enough to have either an ocean or an atmosphere. Now the original earth, on the planetesimal hypothesis, was small and so it could not hold either water vapour or air. It is unlikely that water and air came in with the planetesimals attracted by the growing earth, for if these bodies were like the meteorites that we know they would not contain any volatile matter.

Probably there was little water on the surface of the earth when the first crust was formed because water and molten rock mix in all proportions. Therefore a huge amount of water was contained in the liquid interior of the earth (as there is still). When molten rock comes to the surface it liberates water as it cools—therefore much steam is always disengaged during volcanic eruptions. It seems clear, then, that the quantity of water in the ocean has been increasing during geological time, as fused rock comes to the surface, solidifies and undergoes weathering (see p. 25).

Age of the Ocean. At the end of the nineteenth century there was great doubt as to the age of the earth's crust. Lord Kelvin had made an estimate, based on the rate of cooling of a molten earth, and this gave an age for the earth's crust of about 40 millions of years, far too little in the opinions of the geologists and biologists. Then Joly made another estimate based upon the amount of salt in the ocean. It was assumed that the present ocean was formed by the condensation of water vapour as soon as the permanent crust had cooled well below the boiling-point of water. Now the amount of water entering the ocean in all the rivers of the earth was known; the quantity of sodium contained in this water was also known and the total quantity of salt in the sea was known. It was, therefore, quite a simple calculation to find how long it would require for the rivers of the earth to carry down the known quantity of salt from the land to the ocean: the result was approximately 100 millions of years. This, also, was regarded as too short a period and it was not until the investigation of radioactive substances had progressed for nearly a generation that the latest estimate was made. We believe now that at least 1,000 millions of years have elapsed since the first ocean was formed.

Origin of the Atmosphere. At present the atmosphere contains 21 per cent. of oxygen and 79 per cent. of nitrogen (approx.) with traces of the rare gases argon, helium, krypton, neon, etc. (why there is so little helium is a curious and unsolved problem). There is also, of course, a small quantity of carbon dioxide and a variable quantity of water vapour. Now the original atmosphere probably contained little oxygen and much carbonic acid gas. Plant life was probably abundant soon after the ocean had been formed. There would also be some animal life—even in the absence of oxygen—for we know, even now, organisms that can live in an atmosphere containing no oxygen and we know some that can even assimilate

nitrogen. The abundant carbonic acid gas was probably used up by the primitive, very luxuriant plant life which has the power of absorbing the carbon from the gas and of giving back the oxygen to the atmosphere. Thus the present composition of the latter was established. In some form, of course, an atmosphere is older than an ocean, and the atmosphere that existed when the earth's crust was solid, but still very hot, must have contained much water vapour.

Thus we arrive at the conception of an earth with a rather thin, rocky, cold and strong crust overlying a very hot quasi-liquid interior. From such a condition we must now see if the present features of the face of the earth can be deduced.

The Great Earth Features

First, the earth is an "oblate spheroid." Its polar semi-diameter is about 13 miles less than its equatorial semi-diameter and this is because the form of the earth has adjusted itself to its rate of rotation. When the latter was much greater than it is now the equatorial bulge must have been also greater. As the rate of rotation decreased so the equatorial bulge would become less. This adjustment of the form of the earth to its rate of rotation must have produced important geological effects.

In comparison with the equatorial bulge the other great surface features are relatively small ones; nevertheless they are the things with which we are concerned in our study of physical geography. They are: (1) the regions of earth-elevation, (2) the regions of earth-depression, and (3) the intermediate transitory zones.

The Regions of Earth-elevation. About 29 per cent. of the surface of the earth is dry land, and all this has an average elevation above sea level of about 2,250 feet. Most of this we regard as consisting of the great continental plateaux. On these plateaux are *mountain ranges*, the highest peaks of which attain an elevation of about 29,000 feet. The mountain ranges are made up of folded, sedimentary, or stratified rocks, and among these, towards the cores of the mountains, are igneous rocks which have intruded themselves in a liquid state among the folded strata. Mountain ranges are very generally elongated regions which tend to run in long, gently curved lines. The typical ranges are those that run along the Pacific Coasts (see pp. 178–9).

The Shield Regions. The nuclei of the continental regions are called the "shields." These are regions of moderate elevation—

for instance, "Laurentia" (round the Gulf of St. Lawrence); "Angara" (part of Siberia), Brazil, Africa, Australia, Antarctica, etc. They are not necessarily high regions—thus part of Laurentia is covered by shallow sea. Their characteristic is that *they have resisted the process of folding* (see p. 157). Thus they are, in some ways, parts of the earth crust possessing unusual strength.

The Regions of Earth-depression. These are the great ocean *beds*—those of the Pacific, North Atlantic, South Atlantic, Indian Ocean, Mediterranean and Arctic Ocean. They have an average depth, below sea level, of rather over 2,000 fathoms (or 12,480 feet). Thus the general depth of the ocean is about six times greater than the general elevation of the continental plateaux. On the ocean beds there are depressions of exceptional depth—these are the "deeps" and they may go down to well over 30,000 feet.

The Continental Shelf. The transitory region is that which lies between the continental margins and the 1,000-fathom contour line. This runs fairly close to the continental plateaux (see Fig. 19) so that the area covered by water which is less than 1,000 fathoms in depth is about 10 per cent. of the surface of the whole ocean. All outside (or deeper than) 1,000 fathoms is *ocean-bed.* The zone of continental shelf is transitory, being sometimes land and sometimes ocean (see further on, p. 148).

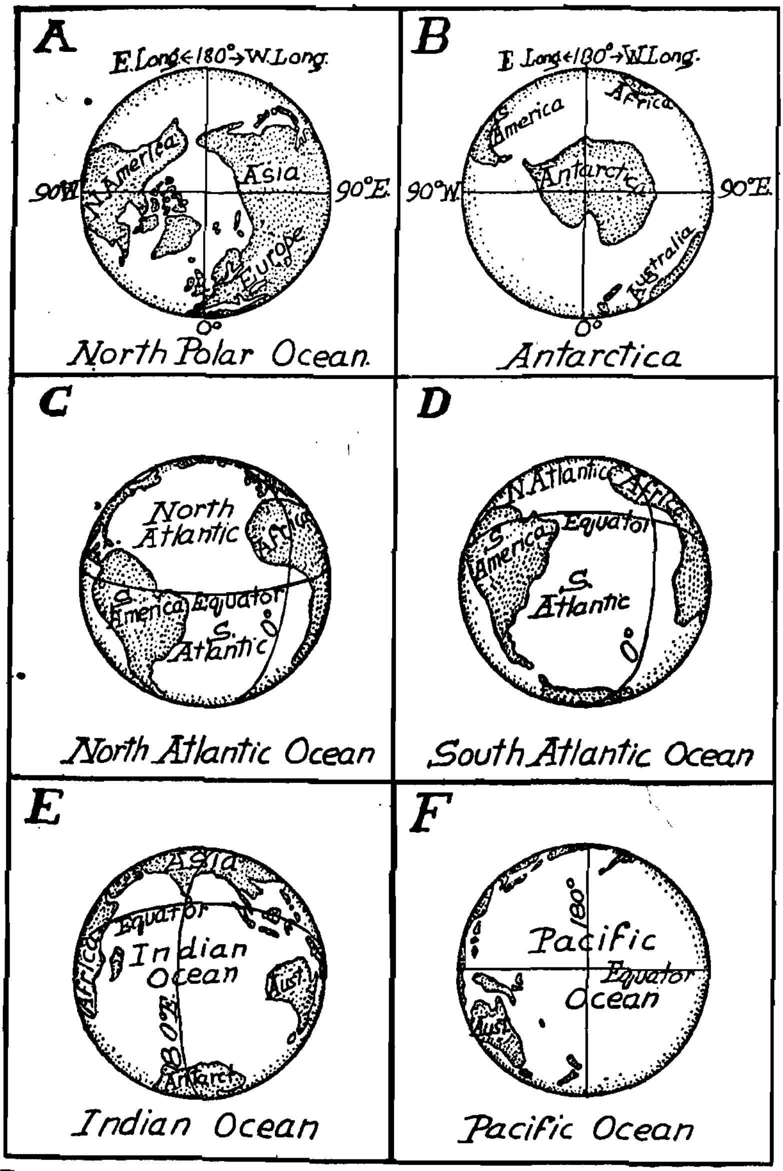
Nature of the Ocean Bed. The zone of continental shelf is covered by materials (gravels, sands and muds) resulting from the erosion of the land—*terrigenous deposits*—or laid down by organisms that live on the sea bottom—*neritic deposits* (shells, corals, etc.). The ocean bed is covered by fine oozes which consist of the skeletons of plants and animals that live in the ocean near the surface—*pelagic deposits.* In relatively shallow water (down to about 2,500 fathoms) these oozes are predominantly calcareous: deeper than this they are predominantly siliceous. What lies beneath the ocean-bed deposits we do not know in the least. We infer that the material is igneous rock of much the same nature as that which composes the oceanic islands (see pp. 161–3). The ocean bed is colder than the continental land (that is, its temperature is nearly that of freezing-point of fresh water) and it is constant. It is more "basic" in character (more of the nature of basaltic rock than that of sandstone rock) than the continental land (which is typically "acidic"). It is more radioactive. It is denser. It is stronger.

The "Face of the Earth"

Now these great terrestrial features of the earth's face have a configuration that is very curious—though it is also very familiar to us. A glance at a map of the earth's surface shows us five great continental plateaux (Eurasia, Africa, North America, South America and Antarctica) and five oceanic depressions (Pacific, North Atlantic, South Atlantic, Indian, Mediterranean and North Polar). Three of the continents, North America, South America and Africa, are triangular in shape, the bases of the triangles being north and the apices south. Eurasia is also roughly triangular, its northern boundary lying not far on either side of the latitude 70° N., its western margin running through Arabia and India towards the Malay Peninsula, and its eastern one being the western side of the Pacific Ocean. Thus there is a tendency for the northern margins of the continental plateaux to be placed east and west, while their other margins run obliquely across the Equator, or across the circles of latitude parallel to the Equator. Even some of the smaller land masses, India and Greenland, for instance, show this triangular form and orientation. Australia rather spoils the symmetry in this respect, while Antarctica has quite another kind of arrangement.

Figs. 1, A to F show what the earth must look like (given good atmospheric conditions) if it were seen through a telescope from about the distance of the moon. First we look at it when the North Pole is nearly central in the field of view (Fig. 1, A). Occupying a considerable region round the axis of the earth is an ocean which is bounded, either by land, or by shallow water lying over a region of continental shelf. (A glance at the sketch chart of the Arctic Ocean, Fig. 23, shows how the polar ocean is bounded by continental shelf extending all the way across from Europe, through Iceland and Greenland to North America.) The northern margins of the continents of Eurasia and North America frame the north polar ocean and stretch round a small circle (that is a parallel of latitude) which is, on the average, about 70° to 75° N. Therefore, in the north, we have an oceanic depression surrounded by continental elevations.

Fig. 1, B shows the view that would be presented if we could see the South Pole also centrally in the telescopic field. Round the axial point, and occupying approximately the same area as that of the north polar oceanic depression, is a continental elevation—Antarctica. We shall see later on (p. 132) that it is not quite



FIGS. 1, A to F. Telescopic Views of the Main Surface Features of the Earth. Drawings made from photographs of a terrestrial globe.

certain whether Antarctica is one undivided land mass or a great archipelago, but, anyhow, it is a region of earth-elevation. It is bounded by *the* great world ocean, a region of sea extending completely round the earth. Into this circumterrestrial ocean extend the apices of the two continents, South America and Africa, and nearly midway between them is the great land-mass of Australia. The curious tri-radiate arrangement of America, Africa and Australia, with respect to Antarctica, has often been noted and it has always had apparent significance when attempts have been made to explain the origin of the features of the earth's face.

Figs. 1, C and D show the views that would be presented if we could look at the earth where the central parts of the North and South Atlantics were respectively in the centres of the telescopic views. The *whole* Atlantic connects together the south circumterrestrial and the north polar oceans. In the south the connection is both wide and deep, but in the north the connections are narrow and shallow. Across between Greenland and Iceland there is a shallow passage—Denmark Strait—while between Iceland and the British Isles there is a wide but shallow sea. Between Greenland and America are Davis Strait and Baffin Bay, but this inlet is nearly closed up, the only communication with the north polar ocean being *viâ* the very narrow series of channels—Smith Sound and Robeson Channel. In addition to these features a study of its geology suggests that the Atlantic presents two oceanic depressions, the north and south ones. There are, however, other interesting conditions in the two Atlantics, and these we deal with on p. 153.

Figs. 1, E and F show the views that would be presented if we could look down at the central parts of the Pacific and Indian Oceans. Like the Atlantic the Pacific connects the southern circumpolar and the northern polar oceans, but the connection is *viâ* a very narrow and shallow passage, Behring Strait. The prominent character of the Pacific is, however, its very great extension. In a telescopic view the marginal lands are so much foreshortened that we seem to be looking at a " water hemisphere." From this aspect the predominant feature of the earth is, indeed, ocean. The Indian Ocean, which is represented in Fig. 1, E, looks like a huge gulf, or bight, of the southern, circumpolar ocean. On the north it has no connection with the north polar depression (though it would not be difficult to trace a past junction with the Mediterranean and then with the Arctic Ocean).

Antipodal Regions. Next let the student look at a small, terrestrial globe. At once he will see that the north polar ocean is antipodal to the south polar continent. The north Atlantic Ocean is antipodal to the Australian continent; Africa and Europe to the Central Pacific; North America to the Indian-Southern Ocean; and the northern land-mass of South America to the West Pacific. Therefore there is a predominant antipodal relation of the great regions of earth-elevation and earth-depression. One must not press this too far, yet it is so apparent that we must believe that it has some meaning.

Such, then, are some of the obvious features of the face of the earth: they assist us in visualizing world-geography as a whole and they suggest interesting questions. Apparently the distribution of land and water is not "accidental"—that is, the result of a great number of small causes which we cannot trace one by one: there are, we suspect, some big, ascertainable causes which may account for the rough symmetry that one can see on studying the earth as we have done. We may now ask why there is land *and* sea; why the ocean does not cover the whole earth with water of a uniform depth; why there is not one undivided land region surrounded by ocean; why regions of elevation and depression appear to be antipodal to each other; why there is a predominance of ocean in the Southern Hemisphere (though there is a south polar continent); why there is a predominance of land in the Northern Hemisphere (though there is a north polar ocean), and so on. We cannot attempt to answer these questions without some knowledge of geophysics, and that is why we have paid some attention, in this chapter, to hypotheses of the origin of the earth and of its internal condition. We may admit, at once, that it is still impossible to give satisfactory answers to the questions that we have propounded, nevertheless so much instructional value lies in the attempt that we must make it.

The Question of the Permanence of the Ocean

The Geological Eras. After the formation of the earth body from the parent sun, and the deposition of the primitive ocean, the superficial rocks became eroded and deposited in the oceans, seas and lakes as sediments. These sediments, hardened into stratified rocks, were perhaps again eroded and redeposited, and so on. Thus the existing metamorphosed and sedimentary rocks that we know

became formed. We know, roughly, the ages (relative to each other) of these stratified rocks and it is possible, in some cases, to estimate their absolute ages. There are four great series of these rocks and the periods of time during which they were formed are called the geological eras. These eras are :—

(Youngest.)
Tertiary, or Cainozoic.
Secondary, or Mesozoic.
Primary, or Paleozoic.
Archean.
(Oldest).

Between the eras, Tertiary and Secondary, Secondary and Primary, Primary and Archean, Archean and the original earth-formative era, there were periods of time characterized by great disturbances about which we know very little. There was life during the Archean period, but we infer its existence from certain materials in the rocks rather than from the direct evidence of fossils. In all the rocks that are younger than the Archean ones fossil remains of plants and animals are more or less abundant, and from the nature of these fossils, and the relative ages of the rocks in which they occur, we can trace the succession of forms of life on the surface of the earth. Observations of the distribution of various forms of animal and plant life in the past also enable us to trace, in some cases, the past distribution of land and water.

Now the student will probably have this question in his mind : have the oceans always occupied their present positions throughout geological time ? That they did so was the general opinion about the middle of the nineteenth century. It was believed that when the first, permanent earth crust formed it fell into a system of regions of elevation and depression. Water, condensing from the original atmosphere, filled up the depressions, which thus became the oceans, and these have, ever since then, occupied their primitive positions with respect to the earth's axis of rotation.

This did not mean that the exact configuration of land and water on the surface of the earth has always been as it is now, because it was well known that huge regions of land consisted of rocks, limestones, sandstones, mudstones, etc., that were stratified and which must have been deposited, as sediments, at the bottom of shallow-water regions. Further, some of these sedimentary rocks contained

the fossil remains of animals which were obviously marine in their habits and so all such rocks must have been deposited at the bottoms of seas. Now vast regions of stratified rock were found over all the continents, even on the flanks and summits of mountains, and so it was obvious that most regions of what were dry land must have been sea bottom at some time in the past.

Round the margins of all the continents there is a zone of shallow sea bottom called the continental shelf, and here the depth is not generally greater than about 1,000 fathoms. This region is not very extensive, covering about 10 per cent. of the total surface of the ocean. It includes, for instance, the English Channel, the Irish Sea, the North Sea, the Baltic, the Gulf of St. Lawrence, Hudson's Bay and a large tract of the North Atlantic extending across between the British Islands and Iceland. Huge regions of the Pacific Ocean, in particular round Australia and New Guinea, are really continental shelf and round all the continents there is a zone of shelf which may be anything from a few dozens to a few hundreds of miles in width. It is on the shelf that most of the sedimentary rocks that have been formed in the past, or are now forming, have been deposited. They result, of course, from the erosion of the land by the sea and from the carriage into the sea, by rivers, of materials worn away from the continental land.

Further there have been many " transgressions " of the ocean over the land : thus a very large part of North America was the locus of a great inland sea during the Cretaceous period. Where this occurred sedimentary rocks were also deposited. Nearly everywhere on the continental plateaux and shallow seas there have been such vicissitudes. During the Tertiary period the British Islands have been joined to the continent of Europe, or have been almost entirely submerged beneath the Atlantic. Yet in spite of such changes the deep ocean beds were regarded as always having been ocean beds—that is, regions of earth-depression, while the continental plateaux were thought about as never having been covered by sea that was more than a few hundreds of fathoms in depth. Relatively to the ocean beds, they were regions of earth-elevation. The continental shelf was always an inconstant region, sometimes being sea bottom and sometimes dry land. Thus there may have been great changes in the exact outlines of land and sea though, in the main, the continents and oceans occupied very much their present positions.

Towards the end of the nineteenth century the belief in the

permanence of the ocean beds was largely abandoned by the biologists and geologists. When the hypothesis of organic evolution by means of natural selection had been generally accepted there was much investigation of the lines of descent of the principal groups of organisms and great attention was paid to paleontology (that is, the study of ancient forms of life): also the geographical distribution of organisms throughout the world was exhaustively studied. Then it was seen that there were many curious facts that were difficult to explain on the hypothesis of permanent oceans. For instance the remarkable pouched animals, or marsupials, occur in Australia and South America, so that from whatever one of these continents these animals evolved they must have migrated into the other. Now a wide and deep ocean was apparently an insuperable barrier to the migration of such typically land animals as marsupials, so that there must have been some land connection between Australia and South America in Mesozoic or Cainozoic times. There were many other examples of the same kind with respect to both land plants and land animals and there were many examples of marine organisms that were known only to inhabit shallow water near the land and which might yet be found on opposite sides of the Atlantic Ocean. Attempts to explain such curious cases of distribution by supposing the migrations to occur *viâ* the Arctic parts of the continents—where the latter are separated only by shallow seas which were certainly dry land at various times in the past—were never quite successful, for the great changes in temperature that would be experienced in the course of such migrations would themselves be barriers to the passage of most land or marine shore animals. There were also purely biological explanations—for instance, the Marsupials *might* have evolved independently in Australia and South America. Such explanations, however, offered very great difficulty and really seem to involve bigger assumptions than those that were made in imagining the existence of "land bridges" connecting the continents.

Therefore the paleontologists have assumed that former continental lands existed—for instance, both North and South Atlantic continents. We give, in Chapter VII, a couple of maps showing these former regions of elevation, one representing the conditions during the Devonian period (part of the Paleozoic Era) and the other during Cretaceous times (part of the Mesozoic Era). It will be seen that very great differences from the present distribution of land and water are here assumed.

Now there are three very curious things in connection with the question of the permanence of the oceans. (1) We know quite well what is the nature of the sediments that are now being deposited at the bottoms of the deep oceans: These are mainly pteropod, globigerina, diatom and radiolarian oozes with the very peculiar red clay that lies at the greatest depths of all. Nowhere on the surface of the earth do we know of any sedimentary rocks that are similar to these oozes. Therefore there is no evidence of a deep ocean bed having become dry land during the geological periods. (2) We have seen that there are "shield lands," or nuclear regions, in all the great continents: for instance, in North America, Brazil, Siberia, Africa and Australia. These are regions of the earth's crust that are very strong—that is, they have resisted the processes of folding that have been largely responsible for mountain building in weaker parts of the earth. Therefore we have, in them, regions that are apparently constant in position, or nearly so. (3) In all the reconstructions of past oceans and continents we are struck with the result that there was apparently *less water on the earth then than there is now.* What these observations may mean we shall consider presently.

On the whole, then, the present general opinion seems to be that the oceans and continents have not always occupied the places that they do now. During the geological periods there have been great continental lands where there are now deep ocean beds. But note particularly that there is no good evidence for the converse statement: that is, we are not convinced that there are any extensive land regions which were formerly ocean beds.

The Origin of Continental Regions

We have not, so far, any satisfactory hypothesis as to the mode of origin of the continental regions: still we must consider those more or less plausible surmises that have been made in the past.

(1) *The Tetrahedral Earth Hypothesis.* It is assumed, with very good reasons, (1) that the earth is very hot inside and is cooling and (2) that an external crust of rock of a hundred or more miles in thickness has now ceased cooling, having attained a constant temperature which is now maintained by the sun's radiation, on the outside, and the slow flow of heat from the centre, on the inside. Therefore this external rocky shell has ceased to contract, while the hot interior earth still continues to contract. Therefore, again, the crust must have become too big for the earth body on which it

rests and it must have gravitated down all the time. It must have adjusted itself so as to rest on the contracting interior body.

A sphere is the body having the smallest surface for a certain volume. A tetrahedron is the body having the greatest surface for the same volume. Therefore, it was argued, the earth surface contracted from the spherical, to some figure approaching tetrahedral symmetry. There were four oceans, Pacific, Atlantic, Indian and North Polar, and these were placed on the faces of the tetrahedron. There were four great earth-bosses, or continental nuclei, North America, Siberia, North Africa and Antarctica, and these were placed at the coigns, or solid angles, of the tetrahedron. Let the student make a model by cutting out four equilateral triangles and then truncating their apices. The truncated triangles can be fitted together, into tetrahedral symmetry, by joining their edges by adhesive tape. The truncated coigns are to be filled up by little cardboard equilateral triangles. The coigns are the continental bosses and the flat surfaces are the oceans. Now the correspondence is not good and if the student attempts to place the tetrahedral figure on a terrestrial globe he will not succeed. Further the theory is unsound, for it cannot be shown that the tetrahedral shape will be one of equilibrium in the case of a contracting sphere. Hence the hypothesis is only helpful.

(2) *Hypothesis of Rotational Instability.* Suppose that in an earth that was solidifying from a fluid or plastic condition there were differences of density from place to place in the interior. Then the centre of gravity might not be the same as the centre of the spherical earth. So the latter would wobble as it rotated. (It does so just now, to a *very small* extent, so that the positions of the Poles are not absolutely constant.) If it wobbled considerably there would be low furrows and ridges on its surface and these would not be parallel to the Equator but would assume figures something like those of the present oceans and continents. But the correspondence between the actual system of elevations and depressions that we see and that which we assume is so rough as to be unconvincing. Further the mathematical theory does not seem to be very consistent with that of a cooling liquid globe.

(3) *Hypothesis of Superficial Yield Zones.* Let the planetesimal hypothesis of earth origin be assumed. Then the earth grew in size by the gradual accretion of planetesimal bodies on its surface—some

very large, others small. As it grew its rate of rotation on its axis must have changed. Also the rate of growth by the falling of planetesimals must have been inconstant: sometimes the rotational speed must have increased, and at other times it must have decreased. With each change of rotational speed enormous strains must have been set up in the solid crust, causing the latter to tend to crack. It need not actually crack, but zones of weakness must have been set up. Now these have been supposed to take certain forms and directions, crossing the Equator obliquely, and radiating out from the Poles just as America, Africa and Australia appear to be situated tri-radiately round the South Pole, while the great con-continental margins cross the Equator obliquely. This hypothesis is plausible—until one tries to fit the theoretical yield zones on a globe so as to make them coincide with the actual continental outlines. Further it depends on the planetesimal hypothesis itself, which has now become unsatisfactory on close examination. It does not appear to be able to withstand close criticism.

(4) *The Hypothesis of Continental Displacement.* More sensational than any of the hypotheses mentioned is that of the actual, horizontal instability of the continental masses. It has been assumed that, at a certain depth below the earth's surface, the rocks are hot and crushed and have so little strength that they must yield to relatively small, long-continued forces. The continents are supposed to *float* on this plastic layer and to be capable of motion on it, much the same as a piece of paper stuck on to the surface of a globe with wet paste could be moved, or slid. It has been assumed that there was originally one undivided land-mass and that, under the influence of some kind of long-continued strain, this broke into various fragments which then drifted apart. Thus the outline of the west coast of Eur-Africa is rather similar to that of the east coast of the Americas, and if the latter continents could be slid across to the east the two land-masses would nearly fit into each other. There would be a gap in the north which could be filled up by the southerly shifting of Greenland. Australia could be made to fit into the Indian Ocean—and so on. To verify such an hypothesis we ought to have some evidence that the longitude of a place may be undergoing change (thus giving an indication of "drift"), and this has been said to be the case with respect to Greenland. Further some competent cause leading to drift of the continents must be found. Tested with regard to the evidence for the change of longi-

tude, and the effect of a small long-continued force in deforming the layers of the earth body that have small strength, this hypothesis has still to be verified. It was originally suggested by inspection of the forms of the oceans and continents, by certain lines of geological evidence, and by the modern theory of isostasy.

Thus we do not appear to have, at present, any established theory of the causes that have produced the distribution of continents and oceans. Such a theory will, no doubt, be made when geophysical research has progressed sufficiently.

The Factors of Earth Movements

Nevertheless much is known as to the physical conditions of the earth and the movements that are taking place in its superficial layers.

Zones of Weakness: Geosynclines. First, there are well-known regions where the earth's crust is obviously weak, the weakness being indicated mainly by the existence of active volcanoes and the occurrence of earthquakes.

Volcanoes are vents by which reservoirs of liquid, highly heated rock, or volcanic magma, communicate with the surface. The reservoirs are distinct ones which do not necessarily communicate with each other and they are situated at no very great distance beneath the surface. These vents are situated in localized regions where the earth's crust is in a state of tension. Cracks are therefore likely to develop, and when such happens magma, from the heated earth-interior, is injected into them and may reach the surface, causing an eruption. Lava is ejected in such eruptions, accompanied by various gases and vast quantities of steam, which becomes liberated from its combination with the magma when the latter ceases to be exposed to the pressures that are imposed on it in its original situation.

Earthquakes are shocks conveyed through the crust of the earth when stratified rocks yield to strains. We shall see presently that the greater part of the earth's crust is in a state of lateral compression and the result of this is that the strata are bent, or folded. Usually this is the way in which these rocks yield to pressure, but occasionally they actually break, forming what the geologists call *faults.* Such ruptures usually happen violently with the result that waves of displacement are propagated, and these constitute the earthquake shocks.

Earthquake and volcanic zones are usually situated on or near to the oceanic-continental margins. Thus all round the Pacific there is such a zone of earth-weakness. Outside the West Indian islands is another. A similar zone runs in a generally east-and-west direction across the tropical Atlantic, through the Mediterranean and Alpine-Himalayan region. Similar regions of earth-weakness occur in island areas—in Iceland, Hawaii and in Antarctica.

Geosynclines very often mark out these zones of earth-weakness. The great example of such a structure is the east coast of the Pacific. Inland there are high mountain ranges quite near to the coast-line and outside the continental shelf there are "deeps," that is, ocean-bed depressions where the depth is greater than 3,000 fathoms. On the west side of the Pacific the geosynclines are situated seawards from the insular arcs (see pp. 159–180). It must be noted that the other oceans do not show the same marginal characters as the Pacific does, but to this matter we return on pp. 205–6.

The Causes of Geosynclines. Now even if we have no good theory of continental formation a great deal is known as to the causes of these great earth-movements which are manifested in vulcanism, earthquake movements of elevation, subsidence, faulting, etc. The original motive force is, of course, the internal heat of the earth body. This is being lost, though very slowly, by conduction outwards through the cold crust. The latter remains at an approximately constant temperature, receiving just as much heat from inside and from the radiation of the sun, as it loses by its own radiation. Having thus become constant in temperature it has ceased to contract. But as we go down into the earth-interior we finally reach a region where cooling and contraction are still going on. This region must shrink away from the outer, cold shell and the latter must continually fall inwards. It cannot do so in the ordinary sense and so it falls into a state of lateral compression which is relieved every now and then by extensive foldings, or bucklings of the strata, or by actual ruptures. The foldings give rise to mountain ranges and the ruptures lead to faulting.

How does all this lead to the formation of geosynclines? Now the ocean bed is different in character from the general continental surface. The latter is warmer and variable in temperature according to the seasons, while the ocean bed is colder and quite uniform in temperature (at about zero Centigrade). Further it is composed of denser materials and it is stronger. Thus it is not, in general, folded

like the continental land is. Yet, like the latter, it must fall inwards upon the underlying contracting earth-interior, and as it does so, it buckles up towards its central parts and curls down at the margin, thus forming the geosynclines. In their typical form the latter are mostly seen in the Pacific region, where the ocean is shallow in the central area, but has marginal, elongated deeps off the coast-lines. Nothing exactly like this is seen in the Atlantic, but there we have a central ridge or Rise (see p. 154) and, on either side of this, great deep basins. Fig. 29 shows, in a very diagrammatic way, the contrast (and similarity) between the two oceans. Why is there this contrast ? Doubtless because *the Pacific is a younger ocean than the Atlantic.*

The Origin of the Continents

Thus, although we can give no satisfactory hypothesis of continental origin, we see that this is bound up with the great movement of contraction of the earth-interior, and the falling in, by reason of its own gravitation, of the outer, cold and non-contracting crust. Why the crust has fallen in, to a greater extent, under the oceans, than on the continental regions, we do not know. And it has still to be explained why the materials of the ocean bed are denser than are those of the continents.

Isostasy. Because they *are* denser, and the reasons for this conclusion must first be mentioned. We measure the intensity of gravity in various ways—say by observing the time of swing of a pendulum of invariable length, set up in various places. The intensity of gravity at any particular level on the earth is proportional to the quantity of matter underneath the swinging pendulum : the more matter, the greater the intensity of gravity. Now we can take two stations, one at sea level on an ocean which is three miles deep and one on the surface of a continental plateau which is, say, one mile above sea level. There is, in any column of, say, one square mile in section, four more miles of height on the continental station than there is on the oceanic one. Sea water has a density of about 1 while ordinary earth crust has a density of between 3 and 4. Therefore the column of matter on the oceanic station must be heavier than that on the continental one. Regions of elevation and depression are *balanced :* thus a high mountain has no more mass than a similar area of low plain, and this means that the materials underneath the mountain must be lighter than those underneath the

plain. Since the intensity of gravity over the oceanic depressions is the same as that over the continental elevations it follows that the materials of the ocean bed are heavier.

Variations in the Volume and Depth of the Ocean

Finally another consideration seems to be important in any discussion of the permanence of the oceans. It is fairly certain that the total quantity of water on the surface of the earth has been increasing throughout geological time. The increased quantity of water comes from that liberated from volcanic magmas brought up to the surface. Now all we have to explain is really a thin film of water on the surface of the earth. Although the ocean is, on the average, about 2 miles in depth, yet, *on the world-scale*, it is a mere film. It may be, then, that continental lands have been submerged in the past by the increasing depth of ocean. But there is another factor which may also be an important one. During geological time the rotational speed of the earth has slowed down by about four hours. Now the earth body must adjust itself to this change in rotational speed, for the greater the speed the greater must be the equatorial bulge and *vice versa*. The quasi-plastic earth-interior will, of course, easily adjust itself, but the crust, being strong, will not do so nearly so easily. The level of the ocean will adjust itself at once. If, then, we have a gradual slowing-down of rotational speed, while, for a time, the crust retains its figure, there must be a flow of water from the equatorial towards the polar regions. Then, when the crust adjusts itself (that is, the equatorial bulge becomes less) the water will flow back from polar to equatorial regions. Worked out quantitatively these considerations may yet go some way towards explaining the vicissitudes in the distribution of oceans and continents that, we may be pretty sure, have occurred in the past of the earth's history.

CHAPTER II

CLASSICAL GEOGRAPHY OF THE OCEAN

What we usually call an historical record is a statement made by some person about things that he has observed, or events which have occurred. The statement may be written in a manuscript, or engraved upon stone, or some other material, or printed in a book. It is usually made deliberately and with the intention that other people who have not made the observations, or witnessed the events, may know about them. Such records are usually the bases of historical works and they are made with the intention that future generations may utilize them.

Now if our knowledge of human affairs in the past were to be based entirely upon such deliberately made records we should not know much more than some of the things that have happened during the last three millennia: as it is, we have much knowledge of man and his doings during the last 20,000 years at least. This latter knowledge we owe to records that were not made with any intention of telling future generations about the things that had occurred—the records are rather the remains than the accounts of human activities. Thus there are ruins of ancient cities buried beneath the Troy about which Homer wrote in the *Iliad*; there are pyramids buried beneath the rotten vegetation of Central American forests; Egyptian tombs contain furniture which was not meant to be studied by explorers but was intended, in some way, for the use of the occupants of the sarcophagi; there are carvings and inscriptions on buildings; imperishable fragments of pottery; flint weapons; charred bones; the refuse of the kitchen-middens and so on. All this takes us back, at the very least, for some 20,000 years, to the time when Cro-Magnon man painted and carved on the walls of his French and Spanish cave shelters. These human remains we piece together to afford us glimpses of the things that men and women did in the times before deliberately recorded history became possible. They tell us what kind of men and women lived then (for we have their skele-

tons); what kinds of houses and shelters they inhabited; what they ate; what animals they hunted and what were the weapons they used in war and in the chase.. And from the distribution of such human remains we can learn about the migrations of man and, knowing something as to the rate at which geological processes go on, we can make rough estimates as to the times when the remains were left in the places where we now find them. Of course such records as those we mentioned above are relatively few and the very fact that they exist is the result of what we may call "accident." It is always difficult to interpret them and occasionally there is much doubt as to what they mean. But we have this consolation for the paucity of undeliberated historical records—when a man sits down to tell others what has happened he can hardly avoid including his own reflections among what he means to be regarded as matters of fact, but when he leaves remains behind him these are evidences of fact only and when we scrutinize them long enough we generally discover what they mean.

Now the slow accumulation of ancient records of the things made and done by prehistoric man has enabled us to reconstruct the maritime history of at least a thousand years before the time when the Homeric poems were written. We are apt to date back knowledge of the ocean to the period dealt with in our most ancient literature, yet it is quite certain that at the time that Ulysses and his companions were venturing out on the River Ocean to find the entrance to Hades other mariners were going much further afield. It was about the period of Solomon, and Hiram, King of Tyre, had navies in the Mediterranean and Red Seas, and a port at Tarshish (in the Atlantic region). His ships brought stone and wood to Joppa for the construction of the great Temple at Jerusalem; gold and silver from East Africa; fabrics, precious stones, rare woods, peacocks, incense, pearls, etc., from the Far East, and even tin and amber from the British Islands and the Baltic Sea. Even a thousand years before the time of Solomon and Hiram, sailor-traders sailed between the Red Sea and the Gulf of Persia, whence they brought commodities carried in Arab ships from India, or even further. And still further back than the times of the early Egyptian dynasties European and Asiatic man must have crossed from Asia to the Australian Continent and its islands and even pushed their way, from archipelago to archipelago, across the Pacific Ocean, perhaps as far as the coast of Central America. They may have crossed the

North Atlantic ocean *viâ* the islands between Scotland and Labrador, or they may have crossed from Asia to North America. Thus, thousands of years before Homer first related the exploits of Ulysses in the little Mediterranean Sea, the most ancient mariners were making voyages compared with which the adventures of the "much-contriving Odysseus" were rather small experiences.

Nevertheless we begin our study of ocean discovery by reference to the ancient Greek literature because it was at this time (so far as we know) that men first thought about recording their experience of what the world was like and speculating as to what it all meant. The ancient Phœnician trader-mariners went about their business without saying much about it. They knew the coasts of Europe and Asia and they could find their ways to the places where they obtained the materials of their commerce, but all this knowledge was guarded jealously from the outside world and it was communicated only to those who were entered into the craft. Yet old men must have talked about the things that they had seen and done in their youthful days and vague and fragmentary notions of the lands and seas and people that existed outside the Mediterranean land fringe must have become common. Probably this semi-legendary description of the outer world was that which formed the material setting of the Homeric epic poems, and it is of extraordinary interest to us, not so much because it represents faintly the more ancient geography, but rather because it suggests what the Greeks *thought* about the world. It is the speculative, rather than the operative navigation and geography of classical times in which we are interested.

The Ocean of Homer. Maps of the world, as known in the time of Homer, show us a kind of oval disc inside which we can recognize the general form of the Mediterranean and Black Seas. Round this water region there is land and bounding the land is the ocean-girdle. Now we must remember that maps are not known before the time of Anaximander (610–547 B.C.), so that representations of the world in Homeric times are, in a way, only graphs of the wanderings of Ulysses and his companions and they are expressions of the knowledge of later times as well as an attempt to represent the ancient geography. Therefore we must not be impressed with the *general* resemblance of the land and water regions in these maps with those of our modern ones. The Homeric world was a great, flat disc with the Sea in its central parts. Round it was land, and in the extreme north dwelt the people called Cimmerians, who lived in perpetual

darkness, " never seeing the sun rise out of the ocean, or decline into it." In this notion of the northern darkness we have the vague memories of hardy travellers who had journeyed towards the Arctic regions. There they encountered fog and snow and cold and they experienced the shortening of the day, more and more as they went to the north. It was a reasonable inference that there would be a region where the sun did not rise at all during the winter months, and this would have been verified (and possibly was verified) by a journey to within the Arctic Circle. Towards the east and west were the lands inhabited by the Ethiopians, whose skins were burnt black by the hot sun and, in fact, there were coloured races to the west (in Morocco and Spain) and to the east (in India). In the south (that is, in Libya) were the Pygmies, and as we know that there are really such tribes in Central Africa it is quite reasonable to suppose that rumours of these peoples had reached Greece, even in the period about 1,000 B.C.

" The Sea," the " Fishy Sea," the " Salt Sea," the " Wide-wayed Sea," etc., in Homer is " Thalassa," always the Mediterranean Sea, and its intimate features are faithfully described. The Ocean (*okeanos*) is the great water stream that surrounds the outer margin of the world. It *flows*, and here we have the suggestion of the strong tides of the northern seas. In the Mediterranean itself the rise and fall of sea level and the streams set up by the tides are hardly perceptible. The tides in British Seas would therefore make a powerful impression on Greek voyagers (as they certainly did later on at all events) and so we get the notion of the great Ocean River or Stream. It is curious that this ocean water was regarded as being *fresh* and as the source of all rivers, wells, springs, fountains, lakes, etc.

Somewhere in the north the waters of the ocean were thought to sink down below the earth as great subterranean rivers (of which Styx was one). Then this underground water came to the surface again, " breaking through the opposing rocks with hollow sound." Why the ancient Greeks should have had this idea of a fresh ocean it is difficult to say unless it were that their only experience of it was the brackish water of the Baltic in their extreme northerly regions.

It is doubtful whether Homer means us to understand that there was a communication between the Sea and the Ocean (as *we* know exists in the Straits of Gibraltar). Thus, in the Descent into Hades, " the ship reached the extreme boundaries of the deep-flowing ocean ; where are the people and city of the Cimmerians, covered

with shadow and vapour, nor does the shining sun behold them with his beams neither when he goes towards the starry heavens, nor when he turns back again from heaven to earth ; but pernicious night is spread over hapless mortals." And again on the return voyage "the ship left the stream of the river ocean and came back to the waves of the wide-wayed sea." These passages (from the 11th and 12th Books of the *Odyssey*) seem to indicate that Ulysses and his companions sailed out from the Mediterranean into the ocean, but the interpretation is not certain, and the maps of the world based on Homer do not show the "Straits of the Columns." The ancient Greeks knew of the ocean because wherever they journeyed far enough over land they came at last to it and it is, of course, very probable that they did actually pass through the Straits.

Never, in Homer, is there any mention of the *further* bank, or margin, of the Ocean Stream. There was, of course, the nearer bank reached by passing over the land. There were, to ordinary sailors, no further margins—to find such they would have had to cross the ocean. Probably there were records of unfortunate mariners who had been blown out to sea and lost and so an impression of disaster and gloom grew up in regard to the ocean. But this was not all. We must endeavour (with, of course, great difficulty) to reconstruct the Homeric cosmogony, and there we get a faint idea of the old dread of what lay beyond the limits of the world. Our conception of the earth as a great sphere unsupported in space, isolated and complete in itself, is of course an extraordinarily difficult one in its origin, however familiar it is to every educated person nowadays (and there are yet men who believe in a "flat" earth). To the Greeks about whom Homer wrote the world had no definite boundaries. In the Universe there was mostly Chaos, "Mother of all things and existences." Everywhere there was being, but only in the world, as it was known to them, was this general being arranged in a cosmos. Outside the world was natural disorder; within its margin was natural order. On the outer verge of the ocean, earth and water and heavens came together and were confused and inchoate, and in this disorder and confusion was the origin of the gloom and dread which brooded over the ocean even until the time of Columbus. Thus, in Homer, the ocean is the place and origin of all mysterious existences ; the abode of happy or unhappy spirits and the approach both to the Elysian Fields and Hades. To us the idea of a world sursounded by a chaos and emerging locally out of chaos is unfamiliar

and even incredible (though to a modern physicist this idea is not so strange). To the ancients it was probably easy and simple: thus, in the Christian tradition there was an earth before the Creation. but it "was without form and void."

But a very little later *(in Hesiod, about 735 B.C.) the boundary of the world is pushed out beyond the ocean. Okeanos is still the* Father of Rivers, compassing all things, but beyond it are "the Islands of the Blessed, by the deep eddies of Ocean." Out to the west were the Islands of the Hesperides where the daughters of Atlas and Hesperis (the Atlantides) guarded the golden apples which Ge, the God of the Earth, gave to Hera. Out in the west, and under the setting sun, in the ocean, was also Erythia, the island where Geryones, the three-bodied giant, kept the oxen which Hercules captured (as he did Hera's golden apples). In the west also, and on the ocean itself, or on its verge, was Elysium the fortunate though monotonous abode of the Happy Spirits, "the meadows of asphodel where dwell the souls, the images of the dead." Thus, not much later than Homer it was believed that there was land beyond the ocean. We shall see later that these legendary islands of the west were (and perhaps are still) believed to exist. Without doubt the reasons for the ancient belief in their existence rested on the involuntary or voluntary voyages across the Atlantic to the Fortunate Islands (The Canaries) or perhaps even to the shores of America itself.

The Early Development of Scientific Geography

Thus we take our ideas as to what was the very earliest geography from the works of Homer and Hesiod. These are, of course, "works of imagination," but we cannot doubt that their material framework rested on stories told by travellers which had passed into tradition and legend: ideas are notoriously difficult to invent and we are hard pressed to think about works of "pure imagination" in which the incidents and descriptions have been really created and not borrowed (and embellished) from things that have actually happened, or which have been observed. We may be sure, then, that Homer was not inventing, in the true sense, the descriptions of the world that we find in his works, but was recalling half-forgotten and distorted experiences of old Greek and Phœnician mariners who had ventured out into the ocean.

Now it is remarkable that the geography of the seventh to the third centuries of the pre-Christian era is as different as it can be

from that of the *Iliad* and the *Odyssey*. The date of composition of these great poems is usually taken to be about 1000 B.C., but so enormous an advance in natural knowledge is apparent in the speculations of the seventh century that we must conclude that the Homeric cosmogony is really that of a much earlier date than the tenth century B.C. This development of physical geography between the time of Thales and that of Eratosthenes we may now notice very summarily.

The Physical Philosophers—Thales to Eratosthenes

Thales of Miletus (about 600 B.C.) gives us a conception of the world which is entirely different from that of Homer and Hesiod. The earth itself is now a sphere unsupported in space. That it was a sphere Thales deduced from the appearance of the earth's shadow seen on the moon during eclipses. He is said even to have predicted the occurrence of eclipses, using the true theory. He made the Zodiac, or path of the sun through the star-constellations, and he made a celestial meridian at right angles to the Zodiac. This advance in nature-knowledge, beyond the shadowy, legendary references which we find in Homer and Hesiod, is so enormous that we simply must refer the cosmogony of the poets to materials of a much earlier period than only three centuries before Thales.

Anaximander of Miletus (610–547 B.C.) was the immediate successor of Thales and he took the huge step forward of constructing the first maps of the earth's surface. Now it is very easy for a sailor to visualize the features of land and sea which he has actually seen: the faculty of so doing is far from being uncommon. But this might be (and often has been) done by men who have never seen a map or chart, and so familiar are we with modern maps that we find it difficult to realize that the earliest charts made and used by mariners are, in a way, only mnemonics aiding them to remember and utilize their experiences.[1] A true map, however, is really a representation, in little, of the part of the earth to which it relates: its features show a "one-to-one" or "point-to-point" correspondence to the "real thing." Such a representation was what Anaximander is credited with having made for the first time.

It is said that he held that the earth was shaped like a cylinder

[1] Thus the "charts" used by the Marshall Islanders are of this nature: they are not really charts, in our modern sense.

and that it was the "upper" flat end of the cylindrical earth which was inhabited and had the Great Sea in its central part.

He also invented the gnomon. A gnomon is a piece cut out from a geometrical figure in such a way that the shape of the remaining part is still the same. Thus our modern gnomon is the little slanting piece of metal that we find as the indicator in a sundial. Its angle to the plane of the horizontal is the same as that of the earth's axis to the plane of the orbit: it stands at 23½° from the perpendicular.

Pythagoras of Samos (about 540 B.C.) carried cosmogony a stage further than the point at which it was left by the Ionian school of philosophers. He believed that the earth was a sphere and that it was not in the centre of the universe (as the later Ptolemaic astronomy held), but that it, along with the sun, moon and stars, revolved round a great central fire. Pythagoras laid great stress on the properties of numbers, which properties were productive of physical effects (just as, in a way, some of our modern exponents of the theory of relativity derive physical conditions, such as materiality, from geometry). Thus Pythagoras held that the earth had the form of a sphere, not because that form could actually be deduced from observations of eclipses or from the appearance of the horizon at sea, but just because a sphere was the most perfect solid body. Anyhow, we have now, firmly fixed in cosmogony, the idea of the spherical earth.

Parmenides of Elea (born 513 B.C.). Next we have quite a new idea, that of the division of the earth's surface into zones, and this was due to Parmenides, the founder of the Eleatic school of philosophy. The earth is a sphere and it has a central and end zones, these being determined by its revolution about its axis or, as the Greeks believed, the revolution of the celestial sphere round the earth. The central or equatorial zone was uninhabitable because of the heat of the sun, and the polar zones were also uninhabitable because of their extreme cold. Between the central and the polar zones were the temperate ones and these alone were habitable. This idea, we shall see, was developed later by Aristotle.

Hecateus of Miletus (about 500 B.C.) we notice because of his map of the *habitable world*: this we reproduce as the sketch-figure 2. It is the first of the world maps, since it came just after the time of Anaximander. It has the circular outline of Anaximander's cylinder-end. In the central part is the Great Sea with its tributaries, the Euxine (Black Sea) and the Palus Maeotis (Sea of Azov).

There is the all-encompassing ocean, flowing round the outer edge of the world disc, but there are now the inlets into the land of this ocean-stream. The strait between the Columns of Hercules (the Straits of Gibraltar) is shown, while the Sinus Arabicus (Red Sea) and the Sinus Caspium (Caspian Sea) also communicate with the ocean. Evidently the latter is now regarded as navigable.

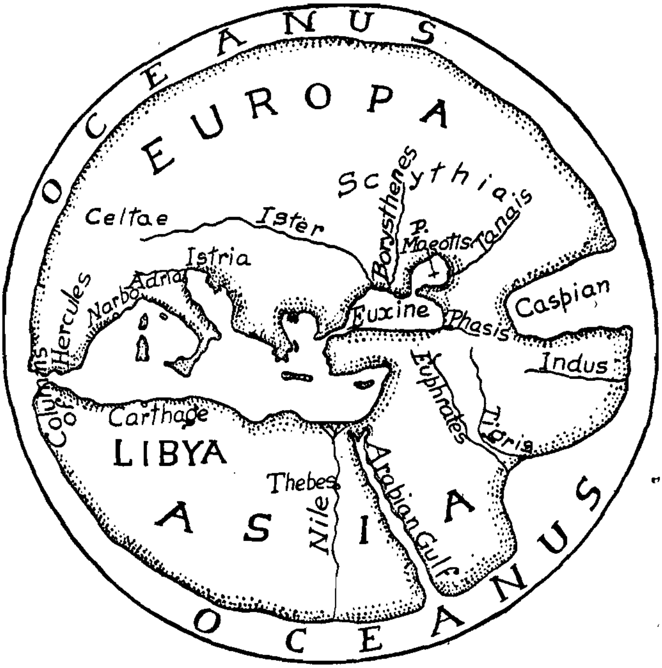


FIG. 2.—Map of the World according to Hecateus.

Herodotus of Halicarnassus (born 484 B.C.) makes a great figure in ancient geography. He was primarily an historian and our interest in him lies in this department of his activity. But he was a great traveller and an acute observer and his own descriptions of what he saw are generally regarded as very valuable. His map of the habitable world is reproduced here in sketch form as Fig. 3, and we see at once the significant change from the map of Hecateus (which was based on that of Anaximander). Into the detailed geography of Herodotus we need not enter, but we notice first that there is no longer the all-encompassing world-ocean. The habitable world is not a great island as it was in the map of Hecateus, but land is now

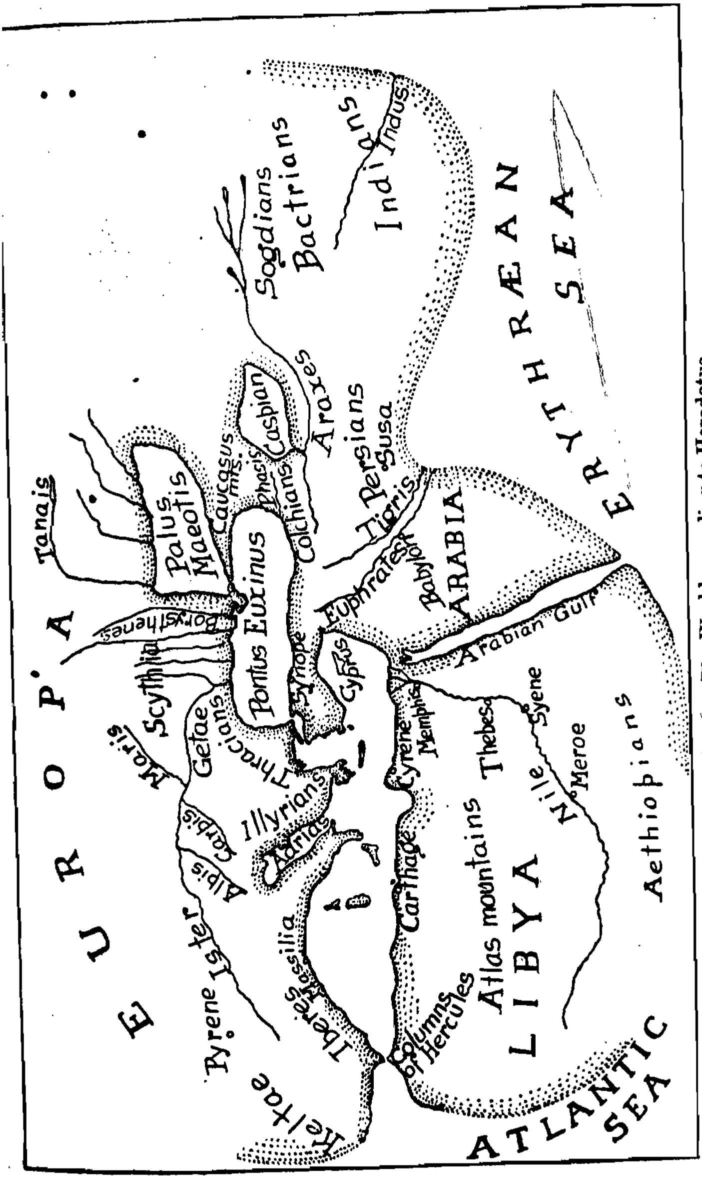


Fig. 3.—The World according to Herodotus.

supposed to extend indefinitely to the north. Libya (Africa) is, Herodotus says, surrounded by water to the south, but nevertheless he was very sceptical as to the belief that it had been circumnavigated by the Phœnicians. This excess of scepticism is very characteristic of Herodotus and (if it were not that reverence for the Greek writers forbids it) we might almost trace an unphilosophic flippancy in the writings of the Father of Historians. Herodotus made fun of those who believed that the ocean surrounded Europe and Asia; he did not credit the accounts of the voyage of the fleet of Necho and he did not believe in the existence of the Casseritides (the Tin Islands of Britain). But in spite of all this the map is much more "modern" than that of Hecateus: where there was ocean there are now the Atlantic, and the Erythraean (Indian) Seas. There was free navigation between the great sea and the ocean, through the Strait of the Columns, and outside the latter, on the banks of the ocean, Herodotus knew of the Carthaginian Colony of Gades (? Cadiz).

Aristotle of Stagira (384–322 B.C.). This very great man took account of so many things that we expect him to contribute to the development of cosmogony and oceanographical science. The spherical form of the earth was now firmly established, but it is noticeable that Aristotle deduces it not only from the appearance of the earth's shadow on the partially eclipsed moon but also from the hypothesis that all material bodies tend to gravitate towards a central point: thus the earth is spherical. Obviously the sun and moon are spherical, and it is natural to suppose that the planets and stars are also of the same form. Aristotle knew that the stars did not change position when seen from places that were far distant from each other (say Greece and Egypt), so that they must, he thinks, be at an enormous distance from the earth. The earth itself he regards as much larger than it was usually believed to be: it might be 400,000 stadia in circumference (that is, 40,000 miles).

The Habitable World

And we now have the distinction between the world and the "habitable world," the latter being the known land and sea round the Mediterranean region. In the geography of Hecateus the habitable world was a great island encompassed by the ocean-stream and outside the latter there was no ordered world—no definite climates, or lands, or seas, but rather a general confusion of things. In the

map of Herodotus we see the world-island lose its definite ocean-boundary so that the margins are now placed much farther away from the known regions. Lastly in Aristotle's speculations the division of the surface of the earth into the zones is firmly established and amplified. We have now the central zone bounded by the two tropics: just a few words about this.

Looking at the path of the sun through the heavens we see that he rises in the east and sets in the west, describing a wide arc in the sky. At the winter solstice [1] (in our northern latitudes) this arc is at its shortest, that is, the sun does not rise so high into the heavens as he will do later on. Between the winter and the summer solstices the sun rises a little higher every day, and from the summer to the winter solstices he rises a little less high each day. There is a latitude in the Northern Hemisphere where the sun rises so high at the time of the summer solstices that, at noon, he is vertically overhead. The path of the sun on that day is an imaginary circle in the heavens, and if we imagine a plane passing through that circle this plane will cut the earth's surface in an imaginary line called the Tropic of Cancer. Similarly there is a latitude in the Southern Hemisphere where the sun is vertically overhead at noon on the date of the winter solstice of the Northern Hemisphere and a similar plane passing through his path in the sky will cut through the surface of the earth in the imaginary line called the Tropic of Capricorn. These tropics are 23½° N. and S. of the earth's Equator and the region of earth-surface between them is the intertropical zone—or simply "the tropics."

Now looking at the sky at night we see one point (very near the North Star, Polaris), round which the stars appear to revolve. Near Polaris the stars describe small circles, but the farther out from the Pole Star we look, the wider are the circles of revolution. At a certain distance from Polaris the stars set below the horizon on the west and rise above it on the east. That circle of revolution of a star which just grazes the horizon was called the Arctic Circle, and if the reader reflects he is sure to see that there must be a different Arctic Circle for each northern latitude. Now look at the sky from the latitude of the Tropic of Cancer (lat. 23½° N.)—the revolution

[1] The winter and summer solstices are the times when the sun makes an apparent pause in his upward and downward movements. For a few days about 22nd December and 21st June there is no apparent change in the height, above the horizon, of the sun at midday. Then the change begins.

circle where a star just grazes the horizon as seen from the tropic is what Aristotle understood by the Arctic Circle. The same reasoning applies, of course, to the Southern Hemisphere where we have the corresponding Antarctic Circles. Nowadays we place the Arctic and Antarctic Circles in latitudes 66½° N. and S. respectively.

Thus, as we show in Fig. 4, the world is divided into five zones :

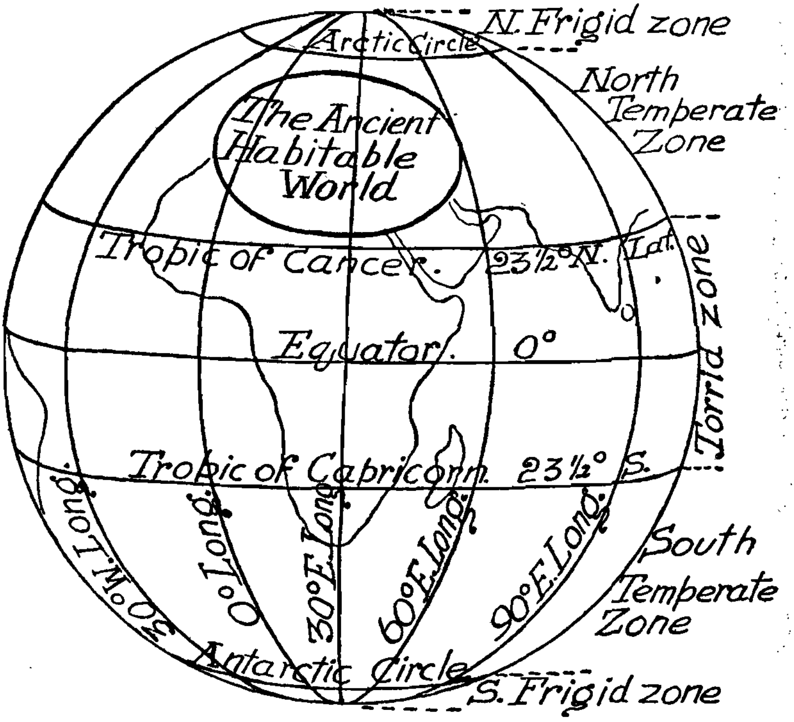


FIG. 4.—The Earth seen from the African Aspect showing the Climatic Zones.

(1) the tropical zone between lats. 23½° N. and S.; (2) the two temperate zones between lats. 23½° N. and S. and 66½° N. and S.; and (3) the two circumpolar zones, which include all the regions between 66½° N. and S. and the Poles. These were Aristotle's zones. He placed the habitable world in the north temperate zone (23½° N. to 66½° N.) and this zone was unbounded since it continued all round the spherical earth. There was, in all probability, a corresponding south habitable world situated between the Tropic of Capricorn and the Antarctic Circle, but, of course, nothing was known about this

(the voyage of circumnavigation of Africa by the Phœnicians not being credited in those days). The tropical zone was uninhabitable because of the intolerable heat of the sun and the circumpolar zones were also uninhabitable because of intolerable cold. Not all of the known north temperate zone was regarded as habitable in Aristotle's time, as we shall see presently. Now this clear conception of the terrestrial zone and climates was a very great step onward in the knowledge of earth geography.

Eratosthenes and the Measurement of the Earth

In the year 323 B.C. Alexander the Great died and the Empire that he had built up crumbled to pieces. Egypt was seized by a Macedonian called Ptolemy Soter, who was followed by Ptolemy Philadelphus, and under these two monarchs in particular the great museum and library at Alexandria were established and developed. The museum lasted, at its best, for only a few generations, but the library had a much longer life, enduring throughout the dynasty of the Ptolemies which ended with Cleopatra, the rule of the Romans, and the disorder of the Barbarians, until it was destroyed by the Saracens. In A.D. 641 Amrou, the commander of the armies of the Caliph Omar, took Alexandria, and Gibbon tells us that the General enquired of his master what was to be done with the contents of the great library : " If," said the latter, " these writings of the Greeks agree with the book of God they are useless and need not be preserved ; if they disagree they are pernicious and ought to be destroyed." So several hundreds of thousands of manuscripts were fed into the fires that heated the Alexandrian baths, and among these were the works of Eratosthenes. What we do know of the speculations of this very extraordinary man is taken from the works of Hipparchus, Strabo, Ptolemy the astronomer and others.

Eratosthenes of Cyrene (276–196 B.C.) was the custodian of the Alexandrian Library, an astronomer and geographer and quite the most remarkable, from our present point of view, of all the philosophers we have had occasion to mention. He knew that the earth was spherical in shape—though, he said, not precisely spherical—and he made a map of the habitable world which we shall notice presently. As to his general works as a physical philosopher we know hardly anything, and only his great achievement in measuring the circumference of the earth has come down to our times, *viâ* the

writings of his successors. Notice, first, what was the astronomy of the period: the spherical earth; the diurnal rotation of the celestial sphere; the independent motions of the sun, moon and planets; the fixity of the stars; the oblique path of the sun with reference to the celestial Equator and rather crude notions as to terrestrial and celestial magnitudes.

Eratosthenes found that Syene (which is our Assouan, or Aswan, on the east bank of the Nile, just south of the First Cataract) was almost on the tropic of Cancer (it is in lat. 24° 5′ 30″, or about 37 miles north of the tropic).

At the summer solstice, therefore, the sun is almost exactly vertically overhead and the gnomon casts no shadow. The Greek observers knew that the noonday summer sun could be seen at Syene from the bottom of a well. Eratosthenes assumed that Syene and Alexandria were situated on the same meridian and that they were 5,000 stadia distant from each other (a Greek stadium is one-tenth part of a mile). All that he had to do, then, was to find the latitudes of the two places in order to be able to calculate the circumference of the earth along their common meridian.

He did not find what we call the latitude, but his observation involved the same principle as we employ. He knew that the gnomon did cast a shadow at Alexandria at noon on the day of the summer solstice and he measured the angle of the shadow in relation to the vertical. The figure and explanation that follow will make this quite clear (Fig. 5). The angle *a* he estimated as being one-fiftieth part of a circle and therefore the arc of the meridian intercepted between Syene and Alexandria was also one-fiftieth part of the great circle passing through the two places. The arc was 500 miles in length so that the great circle was $50 \times 500 = 25{,}000$ miles in circumference. (The circumference of the earth is really 24,899 miles along the Equator.) Eratosthenes, of course, did not know that the equatorial and polar diameters differed in length by 26 miles, though it is curious that he states that the earth cannot be regarded as exactly spherical.

Now it is really surprising that the result of this measurement should have been so very nearly accurate, because all the data are a little inaccurate. Taking the Greek stadium as one-tenth of a mile, the distance between Syene and Alexandria is really 425, and not 500 miles. The two places are not on the same meridian, for Alexandria is about 3° of longitude to the west of Syene. The measure-

ment of the angle of the verticals passing through the two places is nearly right: thus the difference of latitude of Syene and Alexandria is 7° 12′, whereas Eratosthenes made it 7° 5′. Now we might regard the result of this measurement of the earth's circumference as a happy "fluke," were it not that other geographical measurements made by Eratosthenes showed the same fortunate result. What happened was that he did what a modern physicist would do and allowed his inaccuracies of measurement to compensate each other: that is, he took maximum values for the one measurement and

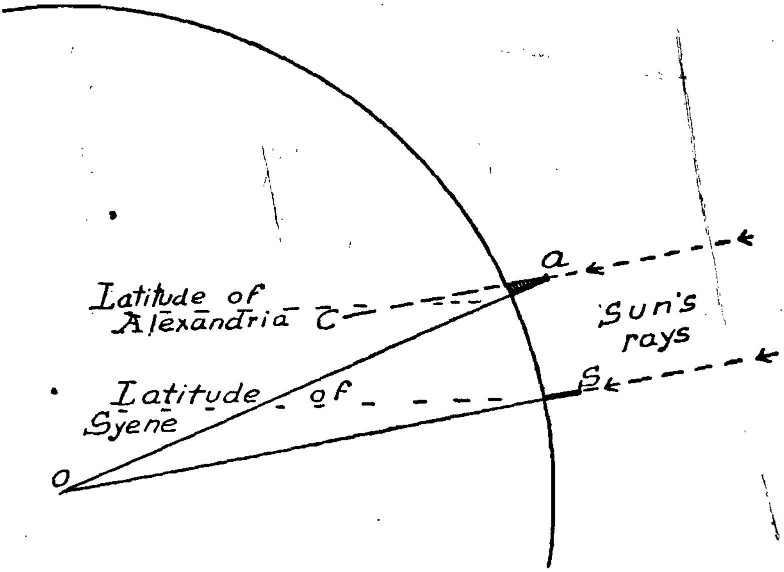


Fig. 5.—The Method of Eratosthenes in deducing the Circumference of the Earth.

minimum values for the other, recognizing that all were approximations. Thus by exercising nice judgment he made the very best of his necessarily rough measurements. He must, after all, have considered the final result to be only an approximate one, for in deducing the length of a degree of latitude he added 2,000 stadia to the 250,000 that he obtained as the value of the circumference. Then each degree contained exactly 700 stadia, that is 70 geographical miles. (It ought, of course, to contain 69 geographical miles.)

The Map of Eratosthenes. Remembering that by a map of the world the Greeks meant a map of the habitable world, we may now

consider that made by Eratosthenes: it is reproduced, as a sketch, in Fig. 6. Taking its larger features first we see that he regards Libya as a peninsula with ocean to the south, that is, he accepts the account of the Phœnician circumnavigation of Africa as true. It is uncertain whether there is ocean or land to the north of Europe, but there is a northern ocean beyond Asia. The Erythraean Sea (Indian Ocean) is continuous with the Atlantic, and to the south of all the habitable world there is ocean: we shall see that Ptolemy, the astronomer, made the serious error of placing land to the south of the Indian Ocean, and this mistake persisted into medieval times, since it was the maps of Ptolemy that came down to us and had very considerable influence on the planning of the voyages of discovery of the sixteenth century.

The huge advance that Eratosthenes made in the construction of maps is, however, his use of parallels of latitude and of meridians: also he gave approximate dimensions for the habitable world. His parallels are not stated in degrees of arc as ours are, but are identified by the names of the places through which they pass. The principal parallel was that of Rhodes: this passed through, on the west, the Sacred Promontory (Cape St. Vincent), which was regarded as the extreme westerly point of the habitable world, and on the east it passed through the island of Rhodes. It is really remarkable (considering how difficult even approximate determinations of latitudes must have been in classical times) that the parallel of Rhodes does run almost exactly east and west. It was the longest dimension, or diameter, of the habitable world.

South from the principal parallel was that passing through Alexandria and then came the parallel of Meroe (which was the capital of a district of Æthiopia and was situated at the junction of the Nile with its tributary, the Atbara River). The most southern parallel was the southern limit of the habitable world and passed through the island of Taprobane (our Ceylon). The most northern parallel was that of Thule. It is a little doubtful as to what island the ancients regarded as Thule, but it is probable that it was one of the Shetlands, for it was said to be about six days' journey to the north of Britain and it is very unlikely that the ships of the classical period could have made Iceland in such a time.

The prime meridian was that passing through Alexandria and Rhodes and produced north and south from those places: as we have seen, it also passed through Syene. Here again the result was

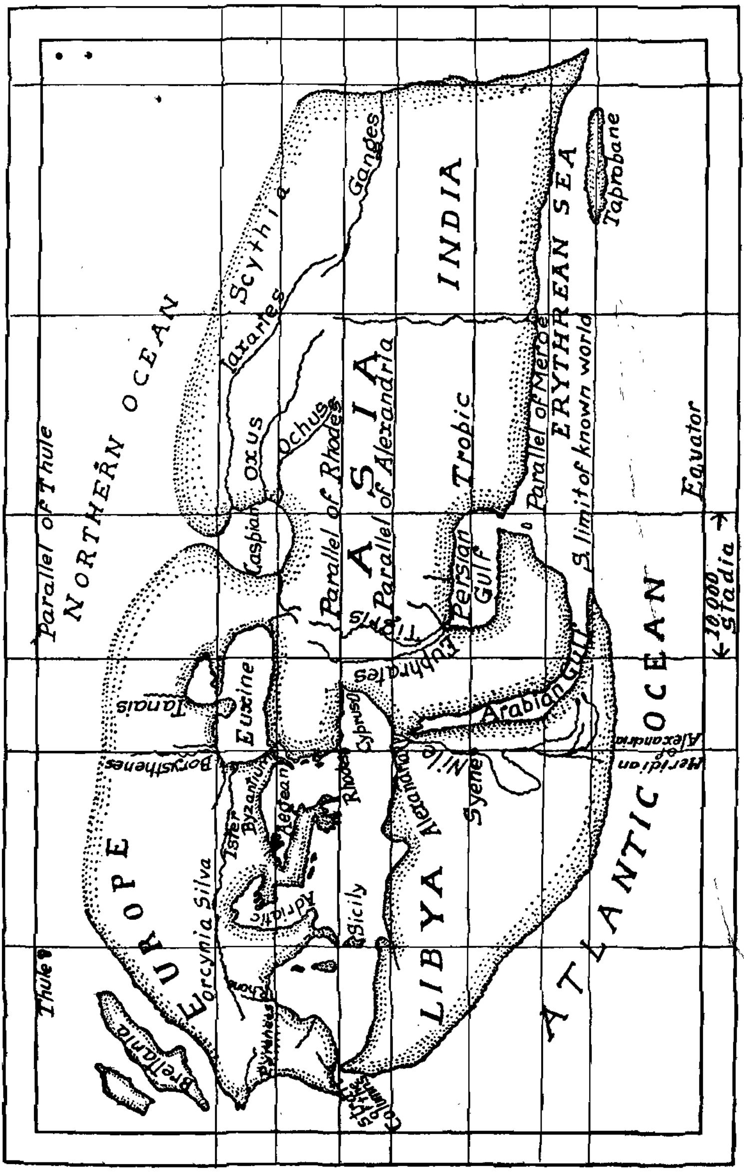


FIG. 6.—The Habitable World of Eratosthenes.

very closely approximate, for Rhodes is only 1° 30′ to the west of Alexandria, while Syene is only 3° to the west. This is even more surprising than the accuracy with which the principal parallel of latitude was laid down, for the determination of longitude was, as we shall see, a far more difficult thing in ancient times than the determination of latitude. The other meridians represented in the map of Eratosthenes give the distances in stadia between the prominent districts and afford us a scale on which to measure up the dimensions of the habitable world.

Extent of Land and Sea. Knowing the equatorial circumference of the earth Eratosthenes was able to calculate the circumference in the parallel of Alexandria: it was 20,000 miles. Between the two oceans—the Atlantic and the Eastern Ocean—was the habitable world, stretched out east and west and about 8,000 miles in length, that is, it occupied rather more than one-third of the whole circumference. The two places on the extreme west and east are Cape St. Vincent (the classical Sacred Promontory) and the coast of India to the north of the Malay Peninsula (the classical Aureus Chersonesus). In the map of Erathosthenes, of course, the Asiatic coast runs nearly north from the Aureus Chersonesus, but in our maps it trends away to the north-east. Now look at a Mercator map of the world and notice that on the parallel of Alexandria the extreme westerly and easterly parts of the old world are the coast of Africa south of the Straits of Gibraltar, and Shanghai on the China Sea. The former is in W. long. 9° and the latter in about 121° E. long., that is, a difference in longitude of about 130°, *or rather more than one-third of the whole circumference of the world in the parallel of Alexandria.* The correspondence is very surprising: Eratosthenes had, very approximately indeed, estimated the proportion which the east and west dimension of the old world bore to the whole circumference. Sixteen centuries later we find Columbus estimating the same dimension in a grossly inaccurate degree.

The remaining two-thirds of the earth's circumference in the mid-latitudes of the habitable world were ocean. In the centre of the world was of course the Great Sea, or Mediterranean, and this was estimated by Eratosthenes as 2,650 miles long, in the east-and-west direction. This was about 600 miles too great, an error of about one-fifth of the whole: some maps of the seventeenth century over-estimate the length of the Mediterranean by as much as one-third. Without the habitable world, then, was the ocean, and now we come

to one of the most surprising utterances of the great geographer: "If," he said, "it were not that the vast extent of the Atlantic Sea rendered it impossible, one might even sail from the coast of Spain to that of India along the same parallel." This remarkable anticipation of the project of Columbus was repeated by the Roman poet Seneca (died A.D. 65). "In later years a time shall come when Ocean shall relax its chains and a great land shall be disclosed. A new Typhis shall find new worlds and Thule shall no longer be the boundary of Earth." Fifteen centuries after Seneca Columbus ventured out on the "vast extent of the Atlantic Sea," fortunately for himself and his companions to find the continent of America athwart his course to India.

After Eratosthenes classical physical geography loses its vigour and initiative. Several natural philosophers need be little more than mentioned in relation to our enquiry.

Posidonius of Apamea (born about 135 B.C.). This was a Stoic philosopher who wrote a treatise on the ocean. He repeated the estimate of the circumference of the earth, using a different method from that of Eratosthenes: he found that the star, Canopus, was just on the horizon at Rhodes while it rose to one forty-eighth of a great circle at Alexandria. Assuming that Rhodes and Alexandria were on the same meridian, this rough determination of latitude gave the circumference of the earth as about 24,000 miles. As in the work of Eratosthenes Posidonius had to deal with errors of observation which compensated each other, but the compensation was evidently not a matter of mental judgment, for the philosopher, on becoming aware of his errors, revised his conclusions and reduced the circumference of the earth to 18,000 miles (about three-fourths of the true value).

Strabo of Amasia (about A.D. 19). Strabo followed the lines laid down by Eratosthenes, but he was more a geographer than an astronomer. In his work, however, we meet with the idea, first deliberately followed (though doubtless attained by earlier geographers) that a map made on a flat surface could not represent accurately the surface features of the spherical earth. Accordingly Strabo insists on the necessity of adopting what we call a method of projection, that is, an adjustment of the parallels of latitude and the meridians of longitude so that the map would show either the true distances, or directions relative to each other, or the true areas of the lands and seas represented on the map. This idea was

followed up by Ptolemy. In the works of Strabo general topography is the main purpose, and with this we are not here intimately concerned.

Pliny the Elder (A.D. 23–79). Here again we have to deal with a geographer rather than a student of the ocean or of cosmography. Pliny was also a naturalist (in our modern sense) and, as is well known, he lost his life while attempting to observe the great eruption of Vesuvius which destroyed Pompeii and Herculaneum in the year A.D. 79.

Ptolemy the Astronomer (*about* A.D. 150). Ptolemy was working at Alexandria in the middle of the second century A.D., but the exact dates of his life period are not known. He was primarily an astronomer and his well-known work was the explanation of the facts of observation in terms of the geocentric theory of the universe. That is, he regarded the earth as placed in the centre of all things. He saw that the sun, moon, planets and fixed stars appeared to revolve round the earth in periods of about twenty-four hours. The sun, however, did not revolve in an invariable path but pursued a spiral course in the heavens between the Tropics of Cancer and Capricorn, while the motions of the moon were also irregular in much the same way. Also the planets did not move in the same way as did the fixed stars. Ptolemy supposed that there were heavenly "spheres" supporting the sun, moon, planets and stars but that the bodies that displayed irregular paths were not actually fixed on the revolving spheres but revolved round centres which were fixed on the spheres. This was the theory of cycles and epicycles which, when it had become sufficiently elaborated, did certainly explain the movements of the heavenly bodies. It was erroneous, as we know, but not until the time of Copernicus was the idea of a sun, fixed in relation to the planets that revolved round it, conceived. Then, very rapidly, the mathematical analyses of Kepler and Newton gave men the true theory of the movements of the heavenly bodies. Until that time, however, the Ptolemaic astronomy was taught and implicitly accepted.

Ptolemy was also a geographer and, just as his system of astronomy was taught throughout the Dark Ages, so also his system of geography was generally accepted. His series of maps became well known, partly because of the great authority of Ptolemy himself and the colleagues and successors who apparently actually made the maps, and also because of the wealth of topographical detail

which was recorded and which was taken as true during the very uncritical period between the first and thirteenth centuries of the Christian era. There was a celebrated Greek astronomer, *Hipparchus of Nicaea*, who flourished about 150 B.C. and who made a map which is the basis of Ptolemy's map of the world. Hipparchus also made a catalogue of stars which Ptolemy adopted and extended. We give here the map of the habitable world which is attributed to the latter philosopher (Fig. 7).

Now the Ptolemaic map makes the enormous step forward of being a projection. The parallels of latitude and the meridians of longitude are not straight lines at right angles to each other, as they are in the map of Eratosthenes, but are curved lines which are not concentric. Obviously a small region of the surface of the globe can be represented on a flat surface by using rectangular co-ordinates which are equally spaced, and that is what we do in making a map of a parish, or even of a county, for the errors involved in treating the parallels and meridians as if they were straight lines at right angles to each other are not appreciable ones. But in a map of the habitable world the errors become very great and so some way of modifying the co-ordinates must be adopted. The way that is usually followed is that devised by Mercator, but we cannot go into the theory of projections here. Anyhow Ptolemy, as Fig. 7 shows, devised a system of projection and he laid down the proposition that a map should be constructed by plotting the latitudes and longitudes of the places identified on the co-ordinate system forming the basis of the map. This would have been quite proper had the latitudes and longitudes of the places been known, but, as we shall see presently, they were not known. Ptolemy gives lists of latitudes and longitudes, but these were not, in general, the results of astronomical observation: they were deduced *after* the places had been laid down on the map in the old-fashioned way. The Ptolemaic system of mapping was one which *ought to have been* rather than was followed in actual practice.

Now the larger features of Ptolemy's map (despite the appearance of accuracy suggested by the co-ordinate system) are greatly distorted. Libya is not an island (that is, the astronomer does not accept the report of the Phœnician circumnavigation) and it stretches away indefinitely to the south. This error was to persist even to the time of Vasco da Gama, and when the Cape of Good Hope had undoubtedly been rounded the great southern land was trans-

FIG. 7.—The Habitable World according to Ptolemy the Astronomer.

ferred to South America. The Indian Ocean, according to Hipparchus and Ptolemy, is enclosed by land on all sides, that to the south being the "Terra incognita" and the great southern continent of the seventeenth century. Beyond Ceylon (Taprobane) is the "Sinus Gangeticus" (the modern Bay of Bengal) and beyond this again is the "Chryse Chersonese" (the modern Malay Peninsula). Beyond the latter promontory is Ptolemy's "Sinus magnus," which is the South China Sea and the approach to the Pacific Ocean. On the extreme west is the Atlantic, or Western Ocean, and we have to imagine what is at the back of the map, so to speak. Apparently the Atlantic Ocean extended to the west, round the globe until it washed the shore of the islands which lay off the coasts of "India trans Gangem."

Now it is important to note the scale and dimensions of the parts on Ptolemy's map. He did not accept the results of the calculations of Eratosthenes, which represented the habitable world and the unknown regions on very approximately their true dimensions, but he took, instead, the inaccurate result of Posidonius who, rejecting the results of Eratosthenes, made the circumference of the earth 18,000 instead of 24,000 miles—thus only about three-fourths of its real size. But also the east-and-west dimension of the habitable world is greatly exaggerated by Ptolemy: thus there are about 180° of longitude between the eastern and western boundaries of the old world, that is, one half of the circumference, and there is still land to the east of India and presumably islands off shore from thence. A voyage from Spain to India, across the Atlantic, with an east wind, would, says Ptolemy, be only 7,000 miles instead of the 13,000 or so calculated by Eratosthenes. These errors were to persist, and become magnified, by the geographers that came just before the time of Columbus, and we shall see that the latter explorer was misled by them into the belief that only a comparatively small distance of ocean had to be traversed by a ship leaving the western shores of the known world for the islands that lay off the eastern parts of India trans Gangem. Columbus willingly accepted the idea of this minimal distance in order to convince his sovereigns that the transatlantic project was feasible, but the root of his optimism was the geography of Ptolemy.

By the time of the latter the real "push" of Greek natural philosophy was becoming spent. Investigation had become formal and systematic rather than a matter of real discovery. Geography had

become a study of mere topography rather than that of great physical features and their origins, and the result was that its bases—the form and dimensions of the great continents and oceans—were not critically examined. From the time of Eratosthenes until that of Columbus there was little real advance except perhaps in matters of detail. After Ptolemy geographical investigation hardly exists and the maps and speculations of the second to the fourteenth centuries are not even of antiquarian interest to science: they exhibit only the debasement of geography owing to a preoccupation, on the part of scholars, with theological controversy.

Classical Methods of Observation

Before we consider how the Greek geographers made their maps let us look briefly at our modern methods. We take the representation of land and sea as it appears on a globe, so that we need not trouble about the various forms of projection. First, then, we make a "framework of reference" on the surface of the globe—a system of intersecting lines of latitude and longitude. There are two fixed points on the earth's surface—the North and South Poles (but see pp. 20-1). Then we draw a line round the middle of the globe so that it is equally distant, at all points, from both of the Poles—this is the Equator. We take another arbitrary point, say the position of Greenwich observatory, and we draw a line passing through this point and the two Poles. This line is our prime meridian and it will cross the Equator at right angles in two points which are at the opposite extremities of a diameter perpendicular to the polar diameter.

Next we divide the Equator into 360 parts, or degrees, and we draw a meridian through each of these. The prime meridian is one of the 360, of course, and it is called 0°. We number the meridians to the west of it 0° to 180° W. and those to the east 0° to 180° E. The meridian 180° W. is the same line as that which we call 180° E. We divide each quadrant of the prime meridian into 90 parts and we draw circles round the globe through these 90 points and parallel to the Equator and we number all to the north of the Equator 0° (at the Equator) to 90° N. (at the Pole), and similarly we number those to the south of the equator 0° to 90° S. At each Pole these "parallels of latitude" contract to points: near the Equator they expand out to a circle of about 24,900 miles in periphery. Thus we make a series of intersecting lines on the surface of the globe (Fig. 4)

which are our parallels of latitude and meridians: this is the "framework of reference" which we use in mapping the positions of places. When a new place (an island, cape, river mouth, etc.) is discovered its latitude and longitude are found and then the position of the place is marked on the globe at the corresponding latitude and longitude as indicated on the framework of reference. Since the earth is very large compared with a globe we divide each degree of latitude, or longitude, into 60 minutes (′) and each minute into 60 seconds (″).

The Determination of Latitude. Suppose that the North Star (*Polaris*) were *exactly* north (it is *nearly* north): then we should see it directly overhead if we were standing at the Pole, but if we were standing at the Equator we should see it exactly on the horizon (if there were no atmospheric refraction). At the pole Polaris would be perpendicular to the plane passing through the horizon (that is, it would be at an angle of 90° to the horizon). At the Equator it would be *on* the horizon (that is at an angle of 0° to the horizon). So if we were to measure the angle between Polaris and the horizon we should find, at once, the latitude of the place where we make the observation. However we do not usually find latitude in this way, but in practice we find the highest point in the heavens to which some particular star (at night) or the sun (during the day) rises. This observation is made on land, by means of a telescope or a theodolite, and on sea, by means of a sextant. The latter instrument is used to measure the angle between the horizon and the lower edge of the sun's disc at the moment when the latter attains his highest altitude (12 noon, local time). By whatever method we make the measurement of altitude some calculations and corrections are necessary in order to find the latitude. With good observations the latter datum can be found to within a few seconds of arc, even from the unsteady deck of a ship.

The Determination of Longitude. Longitude is the angle between the meridian of Greenwich and the meridian passing through the place where the observation is made. The earth makes one complete revolution in 24 hours 0 minutes and 0 seconds of astronomical time. A point on its surface moves through 360° of arc in that time, so that it will move through 360/24 = 15° of arc in one hour. At 12 hours 0 minutes 0 seconds the sun is exactly on the meridian at Greenwich,[1] but we shall have a place to the west of

[1] We neglect some qualifications of this statement here.

Greenwich where it will not be noon for another hour : obviously this place will be 15° to the west of Greenwich. If, then, we can find the moment of noon (that is, the moment when the sun crosses the meridian of the place and attains his greatest altitude on that day) this observation will give us 0 hours 0 minutes 0 seconds of *local time.* But suppose we have a chronometer, or clock which is keeping Greenwich local time, then there will be a difference between the two times. The local noon will be *before* Greenwich noon if we are to the east of Greenwich and it will be *after* noon if we are to the west of Greenwich. Therefore the difference, in hours, between local time and Greenwich time, *multiplied* by 15, gives us the difference in longitude, in degrees, between Greenwich and the place where we make the observation. We call the difference our longitude east or west, according to which side of the prime meridian we are situated.

Thus we can find the longitude if we can find the moment when the sun crosses the meridian and if we know Greenwich time. We find the former datum when we measure the meridian altitude of the sun in the process of finding the latitude : it is the moment when the sun ceases to rise before beginning to fall again. We find the latter datum by carrying a chronometer which keeps Greenwich mean time. Having found the latitude and longitude of a place we can then mark the position of the latter on any globe or maps on which the lines of latitude and longitude are engraved.

Also the master of a ship can find the distance he has sailed during one day (say) by making a calculation from his latitudes and longitudes of points of departure and arrival. He must, however, know also the values of a degree of latitude and longitude. On any meridian a degree of latitude measures nearly 69 miles, and this is very nearly the case with a degree of longitude on the Equator. But since the meridians converge to points at the Poles it is evident that the circles of latitude must gradually diminish as we pass from the Equator to the Poles and so the length of a degree of longitude is variable. It can be calculated, but it is also tabulated so that it can be found, in the books on navigation, for each zone of latitude. Note, however, that the figure of the earth is not *precisely* spherical, so that the length of a degree of latitude is a *little* different in the different zones.

The Measurement of a Degree of Latitude. We must consider this because it is at the root of all terrestrial *and celestial* measurements.

A "base-line" must be measured, and there are now several of these in most civilized countries. The peripatetic philosopher, Dicaearchus of Messina (326–296 B.C.), a pupil of Aristotle, is said to have measured the first base-line, and the measurement of the distance from Syene to Alexandria by Eratosthenes was also that of a base-line. Nowadays such a datum is made as follows: a flat piece of country is selected (Salisbury Plain, in England, and the shore of Lough Foyle, in Ireland) and the ground is levelled over a distance of a mile, or more. The distance between two marks cut on metal, which is let into a block of stone, or concrete, is measured in essen-

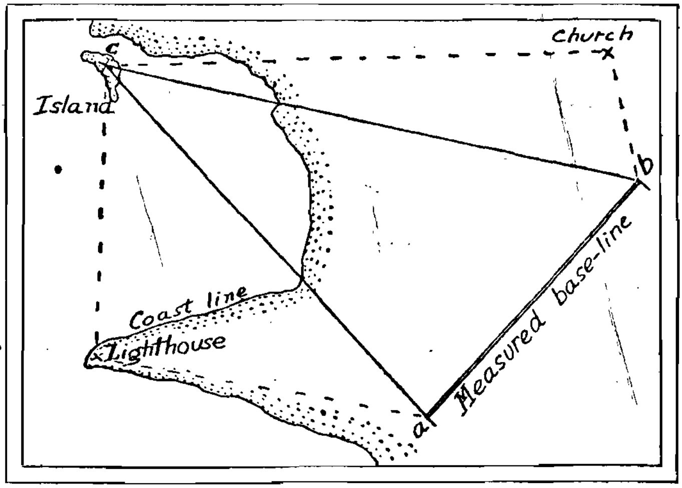


FIG. 8.—Trigonometrical Measurements.

tially the same way that a joiner will measure a plank, that is by laying down a rule. The rulers used in measuring base-lines are metal rods so made that they do not change in length when they change in temperature. Two or more are used and they are not actually laid down end to end. The ends do not touch but the little distances between marks at the extremities of the rods are measured by means of a microscope. In this way the length of the base-line is found with incredible accuracy.

Trignometrical Measurements. Given the base-line we can make further measurements of distances and find positions without actually using measuring rods. Suppose that *ab* (Fig. 8) are the ends of the base: we sight a prominent object, *c*, by means of a theodolite

and find the two angles *bac* and *abc*. The angle *acb* is 180° minus the other two angles. Then by calculations, with which every student is unhappily familiar, we can find the lengths *ac* and *bc*. Taking *bc* as a new base-line we can find other distant points and so on. The whole of the country can thus be covered with a network of triangles, all the apices of which are at known positions and at known distances from each other. Let there be two places, the latitudes and longitudes of which are known from astronomical observation : then we can find, from a trigonometrical survey, the distance, in miles, between them and so we can calculate the length of a degree of latitude or longitude.

The Greek Measurements. Now the Greeks of the classical period had all the mathematical knowledge required for trigonometrical surveying, but their methods of measuring angles (as we do by means of a sextant, or theodolite) were very crude. This is extraordinary because their *craftsmen* (as in architecture, for instance) were very highly skilled, and it is curious that they did not invent and perfect something like a sextant, or that they did not make a good clock. They could not find latitude exactly for the want of such an instrument, and so Eratosthenes could only use the rough measurement of the angle of a shadow cast by a gnomon in order to find the latitude of Alexandria. It is remarkable that his method gave such good results as it did. Further the Greeks could only measure longitude in the roughest kind of way because they had no clocks that kept time with even a rough approximation to a constant rate. They had two ways of finding latitude—that indicated above and the other by finding the length of the day (sunrise to sunset) at the summer solstice. They had a notion of the use of the movements of the moon in the finding of longitude and they could also find the latter (in theory at all events) by noting the difference in time at which an eclipse of the sun or moon was observed at two or more different places. But eclipses do not happen very often and, at all events, the classical measurements of time were far too rough to make the method a practicable one.

Those difficulties of observation were not overcome until the eighteenth century. During the medieval period mariners used the principle of finding latitude that we have indicated above, but they had only very rough instruments wherewith to measure the noon altitude of the sun, so that errors of a few degrees were not uncommon. Not until the modern quadrant had been invented by

Hadley (in 1731) and improved into the sextant by Ed. Halley the astronomer, could latitude be found with an accuracy of a minute of arc or less (a minute of arc corresponds to a distance of one nautical mile). Nowadays, with the beautiful sextants that are used by seamen, the tables that are used in making corrections, and the care with which the observations are made, positions at sea, or on the coast of a country, can be found to a small fraction of a nautical mile.

So also methods of finding longitude were not developed until the eighteenth century. This extreme uncertainty of finding the longitude of a place was a terrible hindrance to exact mapping: thus even after the voyage of Columbus the Cape Verde Islands and the Azores were regarded as being on the same meridian. Not until 1749, when John Harrison invented and made the first good chronometer, could longitude be found with the same accuracy as that of a measurement of latitude.

Classical Determinations of Position

Rough latitudes, as we have seen, could be measured and sometimes approximations to longitudes were also made. But the Greek travellers and mariners depended for their estimations of positions and distances on empirical methods. Even nowadays sailors and fishermen may find their way about without the methods of navigation. A master will, by long experience, be able to say, very approximately, what is the speed of a sailing vessel, knowing the force of the wind, the influence of the tidal streams in accelerating or retarding his speed, and the influence of the ocean currents. He will observe, very accurately, his course as shown by the compass and he will keep a " dead reckoning " of his periods of sailing, his changes of course, etc. The master of a steamship will estimate, very approximately, the speed of his vessel by counting the number of revolutions made per minute by his propeller. Then he has the old-fashioned " log-line," or the modern " patent log," and these instruments give him his speed, by direct observation. Now it was just in these ways that the Greek geographers found distances and positions at sea and on land. So many days' journey, or passage by sea, represented so many stadia traversed, and the directions taken were also observed. Thus the distances between places, and the bearings, in regard to each other, of places could be estimated rather closely *on the small scale*. So the form and dimensions of the Mediterranean were known rather well. It was in respect of the greater

distances—say that between Alexandria and India—that serious error was involved, and here the distortions of the forms of coast-lines were very considerable.

The Itineraries and Peripli. Observations such as those noticed above were recorded in the *Itineraries* and *Peripli*: these are accounts of the details of journeys and voyages. Most of them that we know have come down to us from times that are later than that of Herodotus, but there is little doubt that the ancient map-makers used similar records which are now lost. An itinerary proper belongs typically to the Roman period and it was a description of the routes and the distances from place to place throughout the Empire. The roads were marked by " milestones " so that the distances were fairly well known. All this was done by quite ordinary observation rather than by what *we* call surveying: that is, for instances, the speed of a legion on the march was well known and so also was that of a man riding on horseback. In this way knowledge of local topography may have been very great and, practically, all that was necessary.

A Periplus was the description of a coasting voyage along such a littoral as those of the Erythraean Sea, or the Mediterranean, and it would be just such a work as our modern *Pilots*, or *Sailing Directions*. It would give the details of the coast-line in so far as these were of practical significance—such details as distances (days of sailing) between prominent places; anchorages in river mouths, or bays, or roadsteads; the situations and appearances of islands, straits, shoals, currents, etc. It would also give details of the commercial products of the places or countries included, so that it would be a kind of guide to traders. Thus, we read in the " Stadiasmus of the Great Sea " (the Mediterranean): " From the Calameum to Greas Genu (the old woman's knee) 70 stadia. It is a rugged promontory having a rock on the height: and on the shore there is a tree. It has a place of anchorage, and there is water beneath the tree. Beware the south wind."

One of the best known of the *Peripli*—" Periplus of the Erythraean Sea "—appears to have been written about the end of the Pre-Christian period (in the time of Pliny, 23 B.C. to A.D. 19)—doubtless there were many others of much earlier date. It deals with the topography of the Arabian Gulf (our Red Sea); the Persian Gulf; the Indian Ocean and the coasts of India. It mentions ports and describes the coast-line. It mentions the tidal bores on the eastern

rivers. Although it is earlier than the time of Ptolemy its geographical statements are more accurate, and often when there is a difference between Ptolemy and the Periplus it is the latter which is right. It is not only a kind of *Sailing Directions* but it also contains statements of the articles of commerce dealt with by the ships working on the coasts mentioned. Thus frankincense, myrrh, odoriferous gums, ivory and tortoise-shell were exported from Africa into Arabia, while gold and silver, glass ware and Roman money were exported from Europe to Africa, India exported sandalwood, ebony, muslins, silks, furs, indigo, sapphires and other gems and pearls. And so on. There are even references to the natural history of the countries visited : thus the very peculiar water-snakes of black, green and gold colour, that float at the surface of the sea off the coasts of Ceylon, India and the Malay Peninsula are mentioned—a curious record which must have been received with incredulity by the Romans and Greeks but which, we know nowadays, is one of the best evidences of the accuracy of the statements in the Periplus. Thus the ancient maps were made practically from the accounts of the *Itineraries* and *Peripli* : that is, from positions and distances and directions that were mostly observed in an empirical way. Our method of plotting out the details of an extensive coast-line is by finding the latitudes and longitudes of the important points, say a cape, or river mouth, or village, or mountain, or small island, or shoal, etc. Having got a series of "astronomical fixes," the smaller details are then filled in by obtaining magnetic bearings of places, by trigonometrical surveys, or by actual measurements by surveyors' chains, etc. So the trend of a coast-line can be found with great certainty. But the ancients stated the geographical details which they observed in terms of days' journey or sailing, translated empirically into stadia and rough bearings according to the positions of the sun, moon or stars. They visualized the shapes of coast-lines just as modern fishermen and coastal sailors do, and doubtless their pictures of small regions were quite accurate. But in regard to larger features, such as the coast-lines of the Indian Ocean, these empirical methods of mapping led to great distortion, as the maps that we have reproduced in outline indicate.

Classical Oceanography

Ancient geography was largely the study of topography, that is, the description of smaller, rather than larger natural features. It

had its " humanistic " side, as we see from Herodotus, who, though an historian, yet dealt with the natural features of the lands that he writes about. In this respect it resembles the modern treatment of the subject, where peoples and their distribution and origins; migration routes; trade routes; the influence of natural land and sea features upon migrations and peoples and trade; meteorological conditions in so far as they affect the spread and well-being of populations, etc., are stressed far more than the purely physical side of geography. So, to some extent, modern geography has become a cognate subject with the old-fashioned physical geography and with oceanography, which deals with the geography, the physics and biology of the oceans and seas.

Ancient geography was more general in its scope than any one of our modern divisions of the subject of earth-knowledge. Thus, in the hands of Eratosthenes it included something of our modern science of *geodesy,* that is, the investigation of the form and dimensions of the earth. In the time of Aristotle it included meteorology: thus in the treatise of the latter *de Meteorologica,* we have a description of the *winds.* The Greeks did not use our magnetic directions, N, E, S, W, with the intermediate points, but they tended to refer directions to the places of rising and setting of the celestial bodies, in particular the sun. Nowadays we tend to think about the " components " of a wind, rather than the single air-current itself. Thus we should often find it more convenient to decompose a NNE wind into its components—one having a southerly direction and the other a westerly one (Fig. 9). The Greeks however had twelve winds, which they identified according to their points of origin: the west wind, " Zephyrus," blew from the equinoctial setting of the sun; the east wind, " Apeliotes," blew from the equinoctial rising; the north wind, " Boreas," blew from the Great Bear; the south wind, " Notus," blew from the opposite direction; and so on. These directions, rather than our compass bearings, were their means of orientating any phenomenon, such as a wind, or water current.

Natural History, in our modern sense, was studied by nearly all the old geographers. There are plenty of indications that the Greek sailor and fisherman was a very observant and curious person, attending not only to his proper business of fishing or managing a vessel but also capable of speculating as to the meaning of the kinds of organisms that he saw in the water. There is plenty of this kind of nature-knowledge in the writings of Aristotle and Pliny, some of it

inaccurate (probably because of the mistake of those who made the original lecture notes, or of the later copyists), but very much of it quite sound. There is, for instance, the very curious record of the water-snakes, in the Periplus of the Erythraean Sea, where even the colours of these extraordinary animals were noted. Then there is the remarkable observation made by Pytheas of Massilia (Marseilles), a philosopher who was contemporary with Alexander the Great, on the water of the British Seas. Pytheas visited Thule and there he found the water became thick and sluggish. The thickness of the water is probably exaggerated but such a phenomenon does actually occur. The water may be full of the semi-transparent bodies of floating medusæ ("jelly-fishes"); or it may contain so many minute animal or vegetable organisms (flagellate protozoa, or diatoms) that it may become turbid and smell curiously. These are

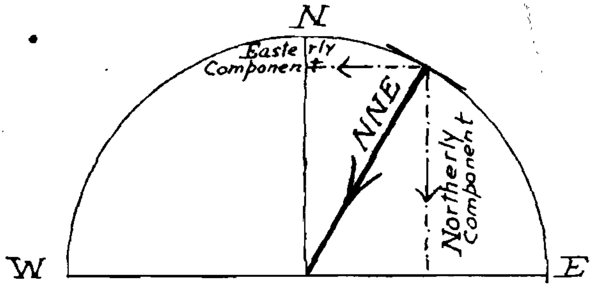


Fig. 9.—Resolution of a NNE Wind into its Easterly and Northerly Components.

only isolated records, of course, but they indicate that the ancient sea-goers did pay much attention to the appearance of the sea water and its contents of animal and vegetable organisms and that occasionally these observations found their way into the writings of the philosophers.

Tides and Currents were observed—the furious current in the Strait of Messina (between the Homeric Scylla and Charybdis), for instance. There are no sensible tides in the Mediterranean itself. There is a rise and fall of the water level that can be detected by modern accurately recording tide-gauges, but this is usually less than the agitation of the water level due to winds and it is not appreciable to sailors or fishermen. Now, in the seas round Britain, the tidal rise and fall, with the accompanying tidal streams, are such conspicuous phenomena that all other things and events connected with operations on the sea appear to hinge upon the tides. Greek

fishermen and sailors and philosophers visiting foreign seas were therefore strongly impressed with the tides and there are several descriptions of these phenomena. It is not unlikely that the rapid tidal streams of the British seas, or the currents that sweep through the Straits of Gibraltar, suggested the first notion of the Ocean-Stream itself, the river of water that flowed round the margin of the world. But, much more significant of ancient observation than that, the tidal rise and fall was very early correlated with the phases of the moon. Pytheas showed that the tides of the ocean increased as the moon's disc increased, and that the tides decreased as the moon waned. Posidonius knew about these lunar tides with the fortnightly periodicity, but he also distinguished between them and the ordinary semidiurnal tides. Then we have the curious observation in the great Periplus of the Erythraean Sea of the existence of "tidal bores," that is, very high tides that rapidly advance as high-crested undulations in the estuaries of great rivers, increasing in height as the estuary narrows. Such tidal bores exist in many parts of the world (even in Great Britain, in the Solway Firth and the River Severn) and the ancient mariners noted their occurrences in the Gulf of Cambay, on the west coast of India.

Even *Oceanic soundings* must have been attempted, for Posidonius gives us a minimum depth for the Mediterranean, in the region of the Sardinian Sea. There, he says, the depth cannot be less than 1,000 fathoms. Both Posidonius and Strabo deal also with *volcanic* phenomena in their relation to changes of level of the land and sea. The former noted the appearance of a new volcanic islet in the neighbourhood of the Lipari Islands (in the Tyrhenian Sea). He observed indications of elevation and subsidence of land in the neighbourhood of the sea and he attributed these changes to the effects of earthquakes. He even suggested that the Platonic account of the lost continent of Atlantis might not be a mere fiction but might represent an actual occurrence. Strabo thought that the island of Sicily itself may not have been separated from the Italian mainland but may have been upheaved from the sea bottom by the fires of Mount Etna.

The period between Hecateus (520 B.C.) and Strabo (A.D. 19) was therefore one in which the study of physical geography made remarkable progress. Had interest in our science continued there can be little doubt that the Greeks would have invented instruments of precision and would have become able to make topographical sur-

veys on the great scale and even to have begun the study of hydrography. As to the reasons why this development did not occur we can only speculate with little success. The oppressive rule of Rome and the spread of knowledge of Christian dogma may have been reasons for the abandonment of physical science. It is said that the philosopher Archimedes was slain by a Roman soldier because, in a fit of abstraction in the study of some problem, he neglected to answer a challenge. This contempt for abstruse studies was probably general among the ruling class in Rome during the Empire. We think about the senators, consuls, pro-consuls and magistrates in much the same way as we think about the types of our own "hard-headed" business men. This indifference extended to religion and it, rather than true toleration of the opinions of others, seems to characterize the spirit of classical Rome: "To the people," says Gibbon, "all religions were equally true, to the philosopher equally false, and, to the magistrate, equally useful." To the alert-minded Greek, on the other hand, interest in the problems of theology was paramount: the "subtle and profound questions concerning the nature, the generation, the distinction, and the equality of three divine Persons of the mysterious Triad, or Trinity, were agitated in the schools of Alexandria." "These speculations, instead of being treated as the amusements of a vacant hour, became the most serious business of the present, and the most useful preparation for a future life." "The highways were covered with troops of bishops, galloping from every side to the assemblies, which they call synods; and while they laboured to reduce the whole sect to their own particular opinions, the public establishment of the posts was almost ruined by their hasty and repeated journies." There was an atmosphere of theological polemic, which seems even to have extended to the ordinary people and preoccupied them, in the third to the fifth centuries, much as the sayings of the philosophers and the works of the dramatists preoccupied the people of the time of Socrates. In such an atmosphere scientific investigation languished so that nothing is lost in making a single step from the second to the fifteenth century in our study of ocean-discovery.

CHAPTER III

THE CROSSING OF THE OCEAN

After the time of Ptolemy, the astronomer, Greek natural philosophy made no further advances and the records of what it did discover, with regard to the natural features of the earth, were either lost or destroyed. Geography became debased in an extraordinary degree, and it was studied anew at the beginning of the fifteenth century because it was not till long after that that the old Greek manuscripts were examined.

The picture of the world exhibited to us in the *Iliad* and *Odyssey* of Homer and the *Theogony* of Hesiod contains little that is definite and it represents the ideas that men had many centuries before the Greek classical period. It is difficult to resist the impression (though we have no positive support for it) that knowledge of the ocean was much more complete in ancient times than is suggesetd in the Homeric poems; that this very early geography was very nearly forgotten and that only a few vague ideas remained to be incorporated in the account of the wanderings of Ulysses. Thus the "Sea" that was so well known in regard to its intimate features—that is, the Mediterranean—is only spoken about as a series of places which were the loci of extraordinary adventures: the island of the winds, the land of the Cyclopeans, Scylla and Charybdis with their terrors, the Planctæ, or Wandering Rocks, etc. Maps of the Mediterranean region based on the descriptions of the *Odyssey* can, therefore, only insert these places into a rudely drawn picture which is really based on *our* geography. But even this shadowy Mediterranean is far more exact than the region that lay outside the boundary of the stream of the ocean. Perhaps we can best reconstruct the most ancient geography by imagining a world of unknown form, only a small part of which was known. This known part was bounded by the ocean and it was an "Economy," that is, something definite and ordered and habitable according to men's ideas at that time. Perhaps there were vast regions outside the ocean stream, but

everything there was indefinite : there might be anything at all, but it was mostly a chaos—regions that were not arranged, ordered, or ready for human habitation.

During the period that elapsed between about the sixth and third centuries B.C. an enormous progress in our notions of cosmogony was made. It was not the fifteenth century that inherited these results of ancient research, but the nineteenth ; nevertheless we have found it useful to summarize them briefly in the two former chapters. What the classical philosophers did discover was therefore:

(1) The shape of the earth, that of a sphere.
(2) The motions of the earth, sun, moon, planets and fixed stars, all referred, of course, to the earth as the centre of the universe.
(3) Rough measures of the magnitude and distance of the sun from the earth.
(4) Close approximations to the size of the earth.
(5) The form of the " habitable world," a huge, insular land region surrounded by the ocean, and with deep inlets into which the outer ocean penetrated—these inlets were the Great Sea, the Gulfs of Arabia and Persia, and the Caspian Sea.
(6) The local geography of the habitable world—this was founded on the experience gained by travellers and recorded in the *Peripli* and *Itineraries*, and it was fairly detailed and approximately accurate.

The world that was unknown—that is, the world outside the " Economy "—might or might not be inhabited. Parts of it, the torrid and frigid zones, were generally thought about as uninhabitable, while the other temperate zone, that in the Southern Hemisphere, was regarded as potentially habitable.

Outside the habitable world region there was continuous ocean. This *might* be crossed by navigators, and even as early as Eratosthenes the possibility that the far eastern part of the world could be reached by sailing over the ocean to the west was entertained—not as a practicable matter but as a philosopher's speculation.

That the adventure of Columbus should thus have been anticipated, but not attempted, by the Greeks is very curious. They were good sailors and fishermen, but they were not good navigators, and they were unadventurous on the ocean. So the wanderings of Ulysses, which seem to us to be voyaging on a very small scale

indeed, appeared to the Greeks of the classical period to be very great doings. If the Greeks had had the inclinations of the predatory Phœnician trader-mariners they could have accomplished great things because they would have combined their voyaging with speculation and description. When we consider their mathematical attainments and their knowledge of physics it seems strange that some philosopher did not invent an instrument that would record time accurately and also something in the nature of our modern sextant. Then they would have had the means of estimating latitude and longitude at sea. With the hints that they had from the practical geometricians of Egypt, and considering the high attainments, in other directions, of their craftsmen, it is curious that they did not make and use instruments of navigation which would have been as good, at least, as those of our seamen of the eighteenth century.

But, again, when we consider the motives that led to the Phœnician voyages, as well as those of the Portuguese, Spanish and English adventurers of the fifteenth and sixteenth centuries, we see that the needs of commerce have always been the strongest incentives to geographical discovery. The desire of material wealth sent the Phœnician vessels through the Straits of Gibraltar to Britain and Africa (and *perhaps* across the Atlantic), as well as from the Red Sea across the Indian Ocean and through the Straits of Malacca into the Pacific Ocean. But, since they were primarily traders, and since their knowledge of the sea was only part of their trading craft, they jealously guarded it from the Greek sailors and they refrained from profitless speculation. And being only traders they attained, in time, a grossness of thought and institutions and a degree of wealth which provoked the antagonism of other nations and made them an easy prey to a less luxurious people. So their end came when, in the year 146 B.C., the Romans drove their plough across the ruins of Carthage.

Thus the influence of the unpractical and speculative Greeks on geographical discovery has been far greater than that of the utilitarian Phœnician trader-sailors who had probably crossed the ocean before Homer was relating the adventures of the much-contriving Ulysses in the little inland sea.

The New Road to the East

Between the time of Ptolemy, the astronomer, and that of Prince

Henry, the navigator, the study of geography (like that of all other branches of learning) languished, almost to the point of extinction. Civilization was again being remade from the crude materials. Even in Ptolemy's period the power of the Empire was declining, and by 410 it had decayed to the extent that Alaric with his Visigoths were able to capture Rome itself. In 451 Attila and the Huns overran Italy, and, in 455, Genseric and the Vandals again sacked Rome. From then onwards the old fabric of ordered States was disappearing and only one unifying power in Europe—that of the Church—existed. Men who did think thought of the world as coming to an end and sought the seclusion of the hermit's cell or of the monastic orders. And, worse still, the new power of Islam was about to appear. In 570 Mahomet was born, and in a few generations what was to become the Ottoman Empire was being established in Asia and Europe. Alexandria, with the remains of its schools, and the great library, was devastated by the Saracens in 641. In 742 the new religious power was so strong that even the Franks had to fight for separate political existence and they secured this when Charles Martel defeated the Moslem armies at Poitiers. The old Empire hardly existed by this time, though its faint shadow, in the form of the Holy Roman Empire, was to appear later. The historical continuity with the institutions of Diocletian was preserved in the Eastern Empire, and from the time of the growth of the Moslem power Constantinople continued to be the bulwark of Europe against the successors of the Caliphs. Then, in the course of time, the Byzantine Empire, ignobly abandoned to its fate by Christian Europe, fell to Mahomet II, on 29th May 1453.

Now it is the consequences of the rise of the Moslem power that we have to notice in seeking for a reason for the revival of geographical discovery in the fifteenth century. It is true that abstract learning continued, to some extent, in the Arabian schools at Basra, Bagdad, Cairo, Cordoba and elsewhere, but the economic straits of the Western maritime peoples led to the extension of scientific investigation outside the bounds of the Moslem dominions. Even before the fall of Constantinople the old trade routes had become insecure to the European merchants. Commodities from the East—ivory, gold, and silver from Africa ; silks, pearls, and gems from India and China ; metals, woods, fabrics, precious stones, spices, etc., from India and the East Indian Islands—came in Arab vessels from the Mozambique Channel, the Persian Gulf, the coasts of India and Ceylon and the

entrances to the Pacific Ocean. These commodities were redistributed from the Persian Gulf and the Red Sea and from there they went to Arabia. There were caravan routes across the Arabian Deserts and along the Syrian coast, and commercial products finally reached Alexandria and Venice either by sea, or through Asia Minor, the gorges of the Taurus Mountains, and then *viâ* Constantinople. With the extension of the Moslem Empire through Persia, Arabia, and along the north coast of Africa towards Spain, these routes became unsafe, and when the Byzantine Empire fell in 1453 they became still more perilous ones. So by the middle of the fifteenth century the Western maritime trading peoples, then Spain and Portugal, began to seek for the new road to the riches of the East, and the result of this quest was the revival of geographical discovery. Of course the " economic motive " was not the only one operative in this revival: there was springing up a great curiosity as to what the world was like outside the familiar boundaries, and this, in itself, was a strong stimulus to adventure and research.

The Semi-fabulous East. Even to-day, when we know so much more about the world, the attraction of " The East " is potent, but in the fifteenth century it was immensely more so. Anything that glittered might be there—" rivers rolling down golden sands, mountains shining with priceless gems and forests fragrant with rich spices " were among the wonders in which the Western world implicitly believed. Wisdom and craftsmanship were there, and there was also an indefinable romance because (though men in the fifteenth century did not know it) it was from the East that the traditions of man's origin had come. Thus adventure and romance and the desire for wisdom and wealth all contributed towards the impulse that sent Europe groping for a sea passage to India and Cathay at the beginning of modern times.

Marco Polo and his Travels. Besides vague reports and traditions and second-hand accounts that came west through the Arab traders there was the highly circumstantial narrative of the travels of the Polos. In the year 1260 Nicolo and Maffeo Polo, two noble Venetian merchants, left Venice and crossed the Euxine to the Crimea. From there they passed the desert to Bokhara, in Turkestan, where they stayed for three years. Thence they travelled into Tartary and to the court of the Great Khan Kublai, who sent them back to Europe with the request that the Pope might send missionaries to convert the Tartars and Chinese to Christianity. That was the first

journey, for in 1271 the brothers Polo, with Marco, their nephew, set out again to visit the Khan's court, taking with them some of the holy oil from the lamp of the Holy Sepulchre in Jerusalem. From Venice they went to Acre and Jerusalem, then through Armenia to the Persian Gulf, through Persia, Turkestan, the Desert of Gobi and, at last, to Tartary and China. They spent three years in this journey, arriving at the court of the Great Khan (in Shangtu, which is not far from the modern Pekin) in 1275. They stayed in the Khan's service until 1292, when they returned home *via* the China Sea, Borneo, the Straits of Malacca, Sumatra, the Nicobar and Andaman Islands, Ceylon, the Persian Gulf, Korassan, Persia, Armenia, and Constantinople. Now even to-day, when all sorts of facilities for travel exist, such an itinerary and variety and length of experience of foreign lands would make anyone a notable person. But in the thirteenth century it must have been an almost incredible thing. However the Polos reached Venice (with shabby clothes lined with precious stones) and at once the wonders of the East became a lure to travellers and an envy to the traders.

Prester John. They brought back confirmation of a belief held very commonly before their time, that there was a kingdom somewhere in Tartary ruled by a Christian king. There had been an original Tartar monarch baptised under the name of John, whose descendants still ruled, holding their territory under the Great Khan, and who were still called by the name of Prester John. This was believed by the early Christian friars and by the Crusaders, and there is nothing incredible in the belief (though it has never been backed up by positive proof) that the Christian religion was, very early in its history, introduced into Tartary, and that the head of the State was also head of the Church. It illustrates very well the curious way in which the love of romance was blended with the motives of the trader that during the fifteenth and sixteenth centuries the desire to visit the kingdom of Prester John was a factor of importance in promoting geographical discovery.

The Medieval Circumnavigation of Africa

The new route to the riches of India and Cathay and the kingdom of Prester John evidently lay round to the south of Libya and thence into the Erythraean Sea. Now Ptolemy's map, which had, up to the beginning of the fifteenth century, been accepted without doubt, made the Erythraean Sea an enclosed region. Libya was continuous

land with that which lay to the east of India and it stretched away south as far as the South Pole of the earth. Yet there was the tradition, recorded by Herodotus, of the Phœnician circumnavigation of Libya from the east to the west (see p. 199) and there were reports from the Arabs, who sailed the Erythraean Sea, of ocean to the south of Libya. The medieval geographers fortunately accepted the traditional evidence in face of the authority of Ptolemy and prepared to sail round Africa. If European vessels could proceed that way to the seas that lay off India, the Spice Islands and Cathay, they had a trade route which, although perilous in the natural sense, was yet safe from the Saracens. So they tried it for themselves.

Prince Henry the Navigator. The stimulus to this exploration came from a very notable man, Prince Henry of Portugal, who was born in 1394. Henry was not himself a seaman, but a landsman who lived at Sagres in the extreme south of Portugal. He says that he was induced to take up the quest of a new route to India when he reflected that neither the mariners nor the merchants could reasonably be expected to embark upon what might be a profitless enterprise, whereas this was just the kind of adventure that should be undertaken by great men and princes. The sentiment was a very worthy one, and it appears also that Henry was not a loser on account of his boldness, for he is said to have established a lucrative slave trade with West Africa. However that may be, he sent out expedition after expedition which slowly felt their way down the African coast.

It was a long time before the Portuguese vessels passed Cape Bojador (which lies just to the south of the Canary Islands). They were, at first, cautious navigators who liked to "hug the shore." Now Cape Bojador is prolonged seawards in a long ridge of rocks, which encourages fierce currents difficult to coastal sailing, and so the vicinity acquired an evil reputation and it became a sort of crucial point in the progress of navigation such that once it had been passed men became much more confident. But there were further terrors down the coast: Hanno, the Carthaginian, who sailed down Africa as far as our Sierra Leone, brought back reports of burning heat and rivers of fire running down into the sea. All these imaginary difficulties had to be repelled before the Portuguese ventured far down the Atlantic Ocean.

But they rediscovered the Canary Islands in 1418, and in 1432

they had rounded Cape Bojador and attained much confidence. In 1446 they reached Cape Verde, and in 1484 Diego Cam passed the Equator, entered the Gulf of Guinea and found the Congo coast. Then they heard about the King of Benin and of a still greater African monarch whose dominions lay further inland and whom they identified with Prester John—a notion that was to tinge more modern speculation and romance. The Portuguese court staked out its claims to the newly discovered countries, asserted their right of monopoly in commerce and navigation and even farmed out the expected trade with the African coastal lands. They sent missionaries, and the desire for the conversion to Christianity of the African natives was really a sincere one. But the great American continent was just about to be discovered by Columbus and to be colonized by the Spanish "Conquistadores," and so, for three centuries afterwards, Africa was destined to supply the human material of a prosperous trade and send generation after generation of slaves to the Americas.

Bartholomew Diaz and the Cape. At last, in 1486, Bartholomew Diaz, with Bartholomew Columbus, the brother of Christopher, as one of his officers, sailed for the south of Africa. He reached the latitude of 40° S. and went 120 leagues to the east of the Cape, rounding it without knowing that he had done so. He saw the famous promontory which, from his experience of it, he called the "Stormy Cape," but which his master, the King of Portugal (who was not a sailor), called the "Cape of Good Hope." He entered the Indian Ocean from the west—a momentous occasion in the history of geography, for by this voyage not only had the route to India by sea been laid open, but the whole western coast of the habitable world, from Thule, in the north, to the Cape of Good Hope in the south (and thus the entire eastern limit of the ocean) had been traversed.

Vasco da Gama. It now remained for some one to take full advantage of these pioneer voyages of the early Portuguese mariner-discoverers, and this Vasco da Gama did in 1497. Utilizing the information obtained by Diaz he left Portugal and in May of that year he doubled the Cape and arrived at Natal on Christmas Day. Proceeding on his voyage he entered the Mozambique Channel (between Africa and Madagascar), where he saw the Arab vessels and was surprised to find how like they were to his own ships. He crossed the Indian Ocean and arrived at Calicut, on the Malabar coast of India, having completed the first circumnavigation of Africa

from west to east and found the way to the East by sea in the direction of south and east.

The Medieval Crossing of the Atlantic Ocean

About this time learning was beginning to revive and the pedants were rediscovering the results of ancient cosmogony and geography. Copernicus, the Polish monk, was twenty-four years of age, and had just taken his doctor's degree at the University of Cracow, when da Gama had reached India. The same spirit of scepticism which was re-enquiring into the Ptolemaic astronomy was also being applied to Ptolemy's geography. Although there are few positive indications of the course of this enquiry, we can be fairly certain that various geographers had re-found the old Grecian suggestions that the eastern parts of the habitable world could be reached by sailing across the ocean to the west. Columbus himself is said to have known of the poetic prophecy made by Seneca some thirteen centuries before his time.

The State of Geography in the Time of Columbus. It was about 1470 that Columbus arrived at Lisbon, his mind teeming with ideas for his project of reaching India across the Atlantic Ocean. Many of his arguments were based on a study of geographical knowledge as it then existed, but there were also a great deal of practical, hearsay evidence that the attempt was likely to be a successful one. Thus there came to the eastern Atlantic islands driftwood of foreign nature, logs of wood carved with what must have been savage implements, great reeds such as Ptolemy spoke about as being indigenous to India—in short just such evidence as *we* have regarded as proving the drift of Atlantic water from the Gulf of Mexico across to Europe. Besides that there were, as we shall see, traditions of former crossings of the Atlantic Ocean. But, in addition to these really very convincing evidences, there were the notions of geography that were current among learned men at that time. Columbus was in correspondence with the Florentine cosmographer, Toscanelli, who prepared the map on which the great traverse was based. This map has never been found, but very fortunately we have the *globe* made by Martin Behaim, of Nuremberg, and this contains the ideas that were in the minds of the scientists of the period. It is reproduced in spherical projection as Fig. 10.

Now we must, in considering the reasons for the optimism of Columbus, think in terms of the geography of the late fifteenth

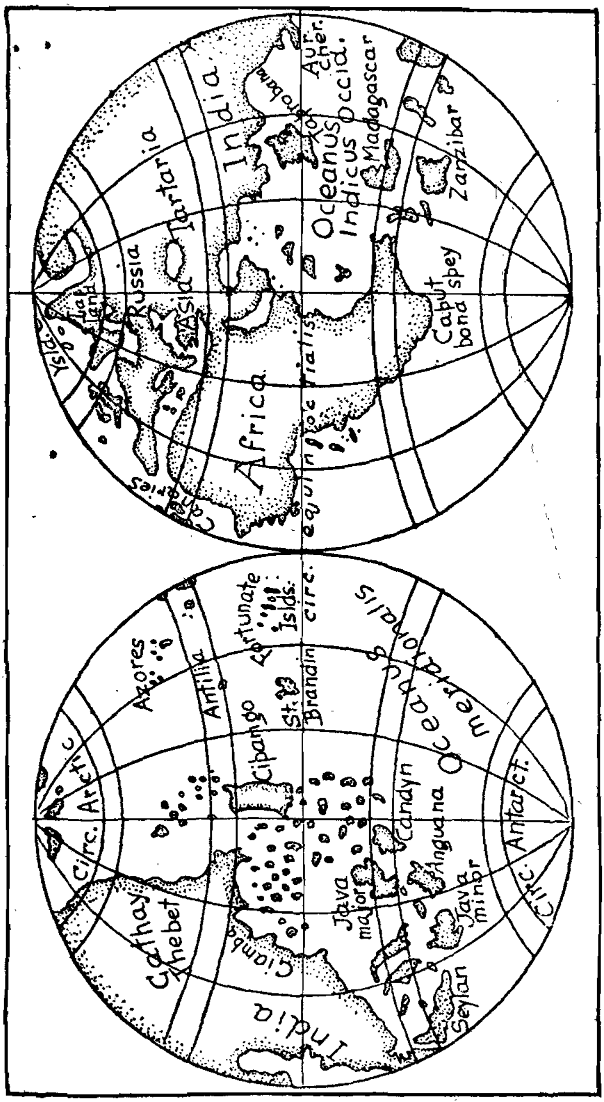


FIG. 10.—Map of the World drawn from the Globe constructed by Martin Behaim in 1492.

century. Behaim's globe shows, then, that the ancient notions of the distribution of land and water on the face of the earth still persisted. The habitable world was still a great Afric-Eurasian island fringed with subsidiary islands. On the north it extended almost to the Pole, but on the south there was a great southern ocean. The enclosed Erythraean Sea of Ptolemy's map had disappeared, for Africa was known to be a peninsula and, instead of the continuous land that joined Africa and far Asia, there was now sea with numerous large islands. Men still believed in the existence of an immense southern continent extending down to the South Pole: this, however, is not shown on Behaim's globe.

Look at a Mercator map of the world: from the Canary Islands across Europe and Asia to China, there are 140° of longitude; from the Canaries, across the Atlantic Ocean to Florida, there are 65°; between Florida and California, across America, there are 35°; and then, across the Pacific to China, there are about 130°.

Therefore, to reach China, going straight east we traverse 140°, little over one-third of the earth's circumference, but in going west to China we must pass over about 220°, nearly two-thirds of the earth's circumference. But take the same data from Behaim's map and we see at once the reasons that appealed to Columbus: between the Canaries and the meridian of the Aureus Chersonesus (the Malay Peninsula) lies the whole Eastern Hemisphere—180° of longitude—and then, beyond the Chersonesus, is India trans Gangem, Cathay and the great island of Zipango (Japan), covering another 105° of longitude. Therefore in travelling by the east to Zipango we should (according to Behaim) travel about three-fourths of the circumference of the earth, whereas we might reach the Eastern Islands by going across the Western Ocean and only going over one-fourth of the earth's circumference. It is clear that the distances across Europe and Asia were greatly exaggerated (the legacy from the Ptolemaic geography, not that of Eratosthenes), and it is probable that, in addition to this source of error, Columbus underestimated the circumference of the earth in the latitude of the Canary Islands. It is also probable that he deliberately minimized the difficulties of his project: had he known and mentioned the real magnitude of a journey west to India he would certainly never have received any support from the court of Spain.

The Early Crossing of the Atlantic. Now it is fairly certain that the American Continent had been reached by European sailors long

before the voyage of Columbus. It *must* have been reached because prehistoric man in the Americas belongs to our modern species and not to any of the extinct ones. He is Mongolian in character everywhere from the Arctic Archipelago to Tierra del Fuego, and so he must have come from Europe, or Asia, to America, *viâ* the islands of the North Atlantic, or across the Behring Strait, or along the Aleutian Islands.

Such were probably undeliberated migrations—men blundering out on the ocean in frail vessels and becoming lost as a rule, but now and then reaching the further lands. Here, however, we are concerned rather with the voluntary voyages made in order to find new lands which men had some reason or other to believe existed. Such were the early Norse voyages to America, told about in the Sagas. It is fairly certain that the Scandinavians really landed in Greenland and began to colonize this island in the tenth century. In the fifteenth century, the descendants of Eric the Red and his companions, in Greenland, were exterminated by the Eskimos. Then a son of Eric, Lief by name, was sent to Greenland as a missionary. He and his companions borrowed a ship and sailed from Greenland west to the land which they expected to exist there. Lief's brothers followed in 1002 and 1005, and between them they found the coast of Helleland (probably Labrador), Markland (which was Newfoundland) and the famous Vinland (Land of the Vine). This was somewhere near Boston and the grapes are supposed to have been bilberries or cranberries. The land, to the Norse voyagers, was a pleasant one, well-wooded, fertile and containing fruits that they had not seen before.

The tradition of Vinland remained with the Norse and was always credited. A Bishop, Erik Upse, is said to have sailed from Vinland in 1121 ; others found a new land west from Iceland, in 1285. It is said that this land was revisited in 1289 and 1290, and it is also said that Norse voyagers again reached Markland in 1347. Lastly there is the tradition of a voyage to Labrador in 1476—just on the eve of the great enterprise of Columbus. All this is very probable, and we shall see (pp. 98–9) that there is other evidence of investigation of the far North Atlantic Islands in the fourteenth and fifteenth centuries by the Venetians and Portuguese before the time of the great Genoese explorer.

The Islands of the Atlantic. Between the European and American coasts lie a number of islands which have become known at different

times. Iceland and Greenland were, of course, known from ancient times, that is, they had been visited and revisited in the ways suggested above. The islands called Friesland in the map of the Venetian Zeno (see pp. 98–9) were probably the Faeroes. Those called Drogeo and Estoliland were probably parts of Newfoundland. Further south were the islands of the Azores Archipelago, which were known from ancient times. These we shall consider later (pp. 164–8) in connection with the physical history of the Atlantic, when we shall also consider the legendary Atlantis of Plato's *Dialogue*.

West from the coast of Britain and Ireland were several legendary islands which have been very frequently mentioned in medieval writings. The British had the tradition of the Isle of Avalon: the Apple-Island (Insula Pomorum). The theme of the apple occurs elsewhere—in the story of the Garden of Eden and in that of the Gardens of the Hesperides where the Daughters of Hesperis guarded the golden apples given to Hera by Ge, the earth-god. Then there is the legend of the lost land of Lyonesse, of which the Scilly Isles are supposed to be the last remnants. The reader should note this recurrence of the idea of a land lost beneath the ocean as the result of a great natural convulsion. We return to it again. West from Ireland also were the islands of Antilia and Brasil, isles which have not been identified but which have given their names to parts of the West Indies and of the continent of South America.

There was also Brandan, or Brendan, which has curious legendary interest but which has not been identified. St. Brendan, or Braenfinn, was a real person—an Irish priest who founded the monasteries of Arafert and Clonfert: he is said to have died in 576. Quite certainly he was a great sailor and an adventurous man and his travels became well known in medieval Irish literature, losing no part of their interest in the telling. St. Brendan went out alone in search of his island. He saw " the mighty intolerable ocean on every side." He saw seas of glassy ice, whirlpools (the Maelstrom), great icebergs, volcanoes covered with cinders and throwing out flames, dark dwarfs (so that he may have been in Icelandic seas, or even in Greenland, and come across the Eskimos). He saw the great whale, on whose " scaly rind " he is said to have spent a night. He saw also the lonely rock where Judas enjoys each year a respite from unremitting torment. Last of all he came to the beautiful island with its trains

of angels; its trees with grape-like apples; its climate where the sun never sets; its great still river, flowing from the north—the Land of Promise.

The Fortunate Islands. From the time of Aristotle there were accounts of islands situated west from the Pillars of Hercules. In the treatise *de Mirabilibus* (attributed to Aristotle but apparently not really written by him) is the mention of such a large, uninhabited island, genial in its climate and with soft and moist winds but without excessive rains; abounding in pleasant fruits; having a rich and fertile soil, such that, even when untilled, it might support a large population—truly an Insula Fortunata. It is difficult not to identify these isles with the legendary Islands of the Blessed, the Islands of the Hesperides, or the Elysian Fields of the Grecian mythology, even if they are not specifically mentioned before the time of Aristotle.

Ptolemy regarded the Fortunate Islands as forming the extreme western limit of the habitable world. They were evidently known in very ancient times. They were rediscovered by the Carthaginians, colonized and then abandoned, and they were rediscovered again and again, finally by the Portuguese, by whom they were colonized and received their present population. *The* Insula Fortunata is, doubtless, Madeira, and the islands are the group which we now call the Canaries. Their aboriginal population is an interesting one, so far as it can now be identified. At present the inhabitants are a mixture with a dominant Berber ingredient, but the aborigines (so far as can be judged from their remains) were quite different. They were people who inhabited caves and who held property in common, but with some kind of patriarchal system of government. They were big men of peculiar skeletal characters, and the most similar race to them appears to be the extinct Cro-Magnons, a people of the Aurignacian, Mousterian and Magdalenian periods of the New Stone Age, whose date may be put as about 10,000 to 20,000 B.C.

Columbus and His Voyage

Thus the Atlantic Ocean was not regarded as a great barren expanse of sea: it presented rather a series of islands which, to the optimistic Columbus, afforded him a number of stages on his way towards the Zipango of Marco Polo. So on his memorable voyage he expected to pick up Antilia or Brasil, but, as we know, he saw

nothing but the " mighty intolerable ocean " in his traverse of over 3,000 miles.

To him the venture was one of comparative ease, but to Ferdinand and Isabella and the courtiers and officials of the Spanish Monarchy it was one of extreme risk and uncertainty. To the mariners who were to sail with him there was still more to be feared. Prejudices, imaginary difficulties, impossibilities and terrors had to be explained away. It was mainly the pedants who no longer believed in the old, flat, disc-shaped earth with the indefinitely extending, inchoate ocean on all sides of it—so the courtiers, officials and sailors had to be convinced that the world was really spherical and that ships going west would not have to climb up a long ascent and then, perhaps, descend tragically down a corresponding slope. Columbus had to adapt his arguments to the mental capacities of his opponents—as when, in the famous trick, he made the egg stand on its end; or when he drew attention to the insects that could walk all round a spherical orange.

The sailors must have been much more difficult to convince, because of the tenacity with which seafaring men of all ages cling to traditional beliefs. From classical times had come the notion that outside the nearer sea the waters of the ocean were thick and sluggish and but little agitated by winds. From some half-forgotten memories of Phœnician wanderings over the Atlantic came the vague, distorted, but well-founded experience of the Sargasso Sea, a region where the ocean was choked by floating weed and through which no vessel could force her way: even in our own time this notion persists and has been the theme of more than one novel. From the legends of the Lost Atlantis (see p. 164) related by Plato came the idea of an ocean shallow and thick with mud and abounding in vast shoals—the remains of the foundered continent. Sailors and fishermen had notions of great monsters of the deep which attacked and destroyed ships (sea serpents based on momentary glimpses of gigantic cuttle fishes and squids). There were floating islands which would sink with those who unfortunately landed on them (perhaps recollections of transitory volcanic islets thrown up to the surface of the sea by submarine eruptions.) There were mountains of loadstone which diverted the compasses of ships, or would attract all iron parts, bolts, nails, etc., allowing the unfortunate vessel to go to the bottom (here we have, perhaps, some mariner's experience of such a region as the magnetic iron deposits of

the Icelandic shallow sea). Imaginary terrors of various kinds were added to those that seamen knew to be real ones, and behind all were the vague apprehensions of the ocean that had come down from the Ancient Greeks—a region of gloom and mystery; the approach to the Infernal Regions; the zone where earth, heavens and sea became confused together, inchoate and terrible. To us it is difficult to envisage the apprehensions with which the fifteenth-century sailors prepared to venture out on a voyage of unknown duration into regions where no man had ever been, or at least from which no man had ever returned.

All these apprehensions Columbus had to argue against and, added to this task, he had to contend with disloyal officers and men who were ever ready to mutiny. His ships and men were requisitioned from Spanish ports by order of the King and Queen, and a proclamation of immunity from civil and criminal proceedings was made to induce sailors to take part in the expedition. The ship of Columbus was therefore " a refuge for criminals and runaway debtors, a cave of Adullam for the discontented and desperate. To have to deal with such a community was not one of *the least* of Columbus' *difficulties.*" That he did so, pressing forwards insistently and calmly on his project without change of plan, without perplexity or irresolution, and above all with the greatest confidence in his own ability as a seaman, excites in every one who studies his career unstinted admiration.

For some of the apprehended dangers seemed to be likely to be realized. There were portents, such as the falling of an unusually great meteorite. The ships did enter the Sargasso Sea, but they easily cut their way through the great plains of weed. Much more serious, however, was the discovery of the variation of the compass. Depending implicitly on this great and unfailing resource of the mariner, we can well imagine the feelings of the sailors of Columbus' ships when they saw the needle change its direction with regard to the Pole Star by as much as a whole point. Surely now they were approaching the legendary mountain of loadstone and at any time the iron nails would fly from the timbers of the ship and disaster would follow. It is said that some prayed that *the Admiral himself* might be standing on deck, clad in his armour, so that he would be the first thing to be drawn off the ship by the attraction of the mountain magnet.

The Variation of the Compass. If the student looks at any modern chart, such as one *representing the* North Sea, he will see that several

compass cards showing the points, and more minute subdivisions into degrees, are engraved on the chart in various places. The north points (which are indicated by ornamental arrow-heads) show the direction in which the north-seeking end of the needle points *near the place where the card is engraved.* The sides of the chart, or the meridians, are drawn *due* north and south, and obviously the needle does not point exactly in these directions : that is to say, it *varies* from the geographical north. And if the several cards engraved on the chart be closely examined (using parallel rulers) it will be seen that the direction in which the needle points differs a little from region to region of the chart. Over small areas it is *sensibly* the same, but even in such a limited region as the North Sea the difference in the compass variation between, say, the Moray Firth and the Bight of Heligoland has significance for the careful navigator.

The fact that a magnetized needle points in one direction means that the earth itself is a magnet and that it has North and South Poles. If the magnetic poles were in the same places as the geographical poles, then the needle would point, everywhere on the earth, exactly due north and south. But the magnetic poles differ in position from the geographical poles and are not fixed, and there are *two* of them in the north and two in the south. Now the result of this is that the compass needle does not point to the geographical pole (because the latter is not the directive magnetic point), nor does it point exactly to either magnetic pole (because there are two of these and *both* of them attract the needle). The angle between the direction of due north (which is very nearly that of the star *Polaris*) and the direction of the needle is called the *variation of the compass.*

The whole thing is still more complicated by the fact that the variation is not constant. Take any one place (say Gomera, in the Canary Islands) : the variation there, at present, is 18° to W., but it is decreasing at the rate of 4 minutes of arc annually. After a time the compass will point exactly to the north and then it will slowly change over to the east. This is because the positions of the magnetic poles, and the intensities of their magnetic forces, are not constant. Fig. 11 shows the magnetic chart of the Atlantic Ocean. As the results of many very careful surveys the amount of variation at a great number of places has been observed and also the rate at which the variation changes. Now each of the curved lines passes through all the places where the variation is the same.

Having such a chart in his possession the master of a ship can, therefore, convert his observed compass bearings into "true" ones by adding or subtracting the variation. Thus if the observed bearing were north, 24° W., and if the variation at the place of the ship were 16° W., true north would be 24°+16° to the west of the course on which the ship was sailing. This correction must always be made (except in local navigation, where the master works according to magnetic bearings), and the whole thing—which is really more complicated than we have indicated here—is a terrible bother to the young man who is preparing to become a master-mariner!

Now look again at Fig. 11, where the thick, dotted line shows the approximate course of Columbus across the Atlantic Ocean, and the thin curved lines show the compass variation. Of course we cannot be sure what were the variations in 1492, but suppose, for the sake of illustration, that it was much the same as it is to-day. A ship starting out from Gomera, in the Canary Islands, would have its compass pointing about 18° to the west of true north, that is, it would point to the west of the North Star, *Polaris*, but when the ship reached the meridian of about 75° W. the variation would have decreased to zero and the compass needle would then point due north, or directly toward *Polaris*. Proceeding on her course the vessel would attain the meridian of about 85° W., and now the compass would again exhibit variation, *but it would be to the east*, and for some distance west this easterly variation would increase. To us the phenomena are well known, taught in the navigation schools and drilled into the mind of every sailor-boy, but to the mariners of Columbus the appearances must have been most terrifying. Of all things they depended on their compasses, and now these instruments were failing them.

The Admiral had to make an explanation which would account for the behaviour of the compass and so satisfy his men. He told them that the needle was still true, but that it was the star *Polaris* that was inconstant, since it really revolved round the true north pole of the heavens. Apparently the men accepted this hypothesis, but to Columbus himself it must have introduced appalling difficulties, for he must have known very well that *Polaris* was very near indeed to the celestial pole. He had other notions himself, for various phenomena suggested to his mind that the earth itself was not truly spherical in shape. Somewhere to the west of the Pope's line (see p. 93–6) there was a sort of terrestrial nipple rising up towards the sphere

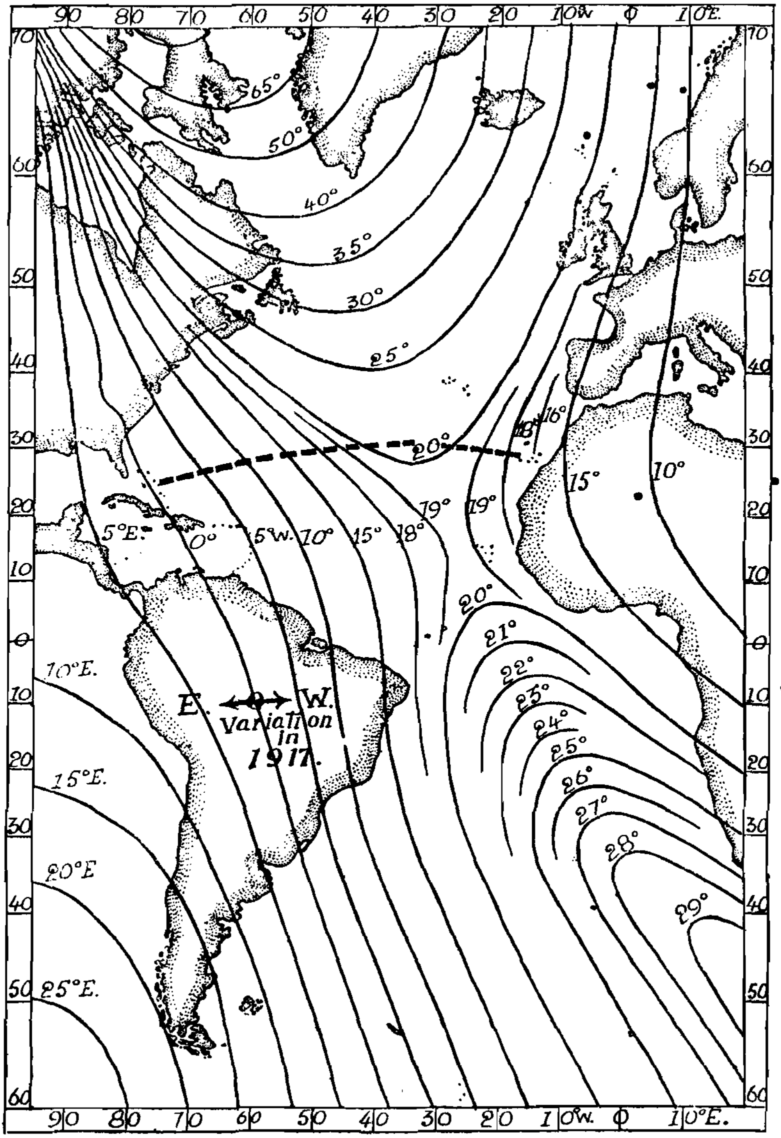


Fig. 11.—The Atlantic Ocean, showing the Approximate Track of Columbus' Ships and the Magnetic Variations (in 1917).

of the moon (on the Ptolemaic astronomy), and in the neighbourhood of this elevated part of the earth he did really sail uphill, so to speak. Now it is curious that exact, modern geophysical research has, indeed, shown that the earth is not spherical. It is, of course, about 26 miles greater in diameter round the Equator than it is along the line passing through the two Poles. Also the Equator is not a true circle, because there is a protuberance, or nipple, in North Africa. This elevation is, of course, very small, and it is not easy to detect. Still the coincidence between this result of modern geodetic surveying and the hypothesis of Columbus is a quaint one.

The Facts of the Voyage of Columbus. The expedition sailed on Friday, 3rd August 1492, and made the landfall on 12th October 1492. *The departure* was the Island of Gomera, in the Canary group, in lat. 28° 10′ N. and long. 17° 25′ W. *The landfall* was the island in the Bahama group called San Salvador by Columbus, Guanahani by the natives, and marked as Watling Island on the English Admiralty charts, lat. 24° 10′ N. and long. 74° 25′ W.

The course was West 5° South.

The distance traversed was 3,105 miles (the great circle).

The maximum speed was 8 knots.

The average speed was about 4 knots.

The voyage lasted 35 days.

The Discovery of the East American Coast. This need not concern us greatly. Columbus himself, on his third voyage, in 1503, sailed along the coast of Central America. Balboa found Venezuela. Vespucci Amerigo, who appears to have been a provision merchant and not a sailor at all, sailed along the north-east coast of South America and, by a curious chance, gave his name to both continents. Sebastian Cabot, in 1497, before Columbus himself had seen the Spanish Main, had discovered Newfoundland. The Spanish Conquistadores rapidly exploited the regions of Mexico and Peru, and in a few years the whole of the western side of the Atlantic from Labrador to Patagonia had been traversed, and though it required other four centuries before it became the " great herring-pond," it had become a waterway from land to land. The " ocean " became confounded with the familiar and homely " sea," and Columbus was called the " Admiral of the ocean-sea."

The State of World Geography immediately after Columbus. It was still doubtful what was on the other side of the ocean-sea. In 1507

Ruysch made a " mappa mundi " in which every land feature is still greatly distorted because India was supposed to be just beyond the newly discovered American land. We have, in fact, something very like Behaim's globe except that there is now a great continental land, called the New World, on the other side of the ocean-sea, and the hypothetical strait leading into the sea that lay off India is shown. Leonardo da Vinci, who was interested in everything, is said to have made a map (Fig. 12) showing America as a great island and with wide openings on the north and south joining the ocean-sea with the Indian Ocean. Johann Schöner, who was Professor of Mathematics

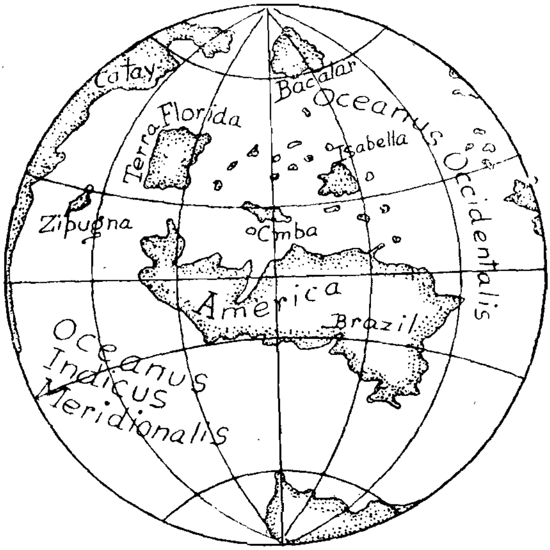


FIG. 12.—Map of the Atlantic attributed to Leonardo da Vinci, 1515.

at Nuremberg, made three maps : the first (1515) shows the various continental American islands and the straits leading towards Zipango, and the second (1520) shows much the same conditions. But in Schöner's third map (Fig. 13) the American Continent has come to assume the shape by which we recognize it. This was, however, after the voyage of Magellan. Columbus himself did not realize that he had really found a new continent beyond which, and between him and Zipango, lay a new ocean. He coasted along Cuba, believing that, in this island, he had found the promontory called the Aureus Chersonesus. He did not know that after his voyage west to find India he was now further from that land than when he left

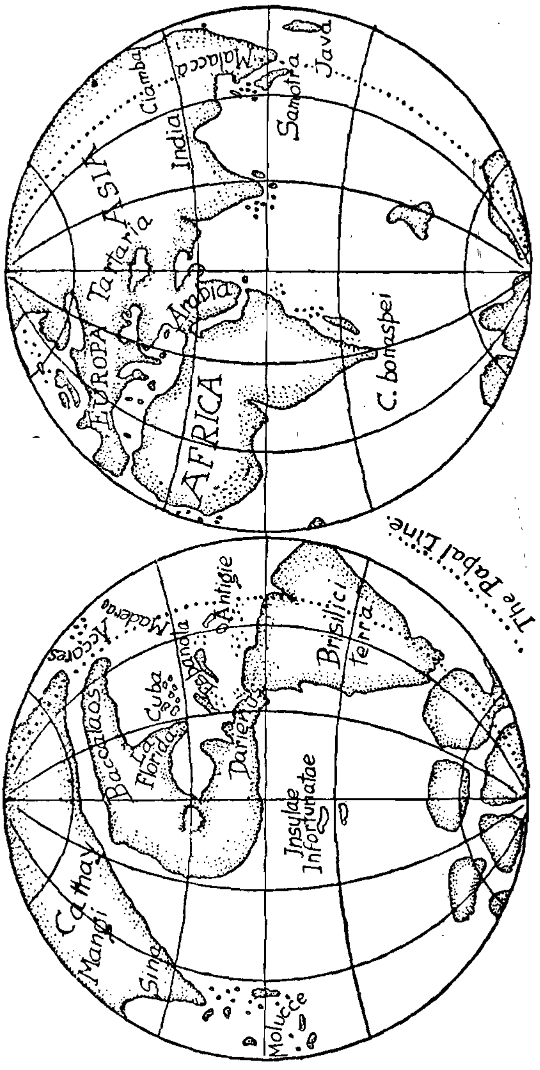


FIG. 13.—Map of the World. From a Globe made by Schöner in 1523.
The "Papal Line" is the one that was adjusted in 1494. See p. 96.

Spain. All the while he sailed off the coasts of the Spanish Main and Central America he was looking for the strait that would lead into the Indian Seas. The finding of this strait and the realization of the vast distance that still lay between America and Zipango were essential to the making of a true world-map.

The Finding of the Strait. Now the straits leading from the Western into the Eastern Ocean did really exist, and it is curious to reflect on the enormous distance of coast-line that Columbus would have had to traverse before he could enter them. Sailing north he would have had to pass Cabot's "Prima Vista" (see p. 99), enter Hudson's Bay, pass through Fury and Hecla Strait (see Fig. 17) and then through Bellot Strait, rounding Boothia Peninsula, the extreme northern part of America. On the south he would have had to coast along the whole South American Continent before he would have found the strait between Patagonia and Tierra del Fuego. Between these two passages, 172 degrees of latitude apart, lay some 12,000 miles of unbroken coast-line. But he thought that he would find his passage through the narrow neck of land that we now call Panama and which his immediate followers called Darien. Traversing this coast-line he came to the islands off the mouth of the Bay of Chiriqui, and there he spoke with the natives, who told him that nine days' journey to the west there was a great sea. Columbus did not make that land journey because he was a sailor and it was a passage for his ships that he was seeking.

The Discovery of the Pacific Ocean

Keats, the poet, tells us that "stout Cortes," with eagle eye, "stared at the Pacific—and all his men looked at each other with a wild surmise—silent upon a peak in Darien." It was, however, Vasco Nunez de Balboa, who, first among the medieval explorers, saw the Pacific Ocean.

The administration and exploitation, by Spain, of the American Colonies is not pleasant reading, and one realizes, in even glancing at this part of history, how very few men there are who do great things in the interest of pure learning. The history of America, for the century after Columbus, is that of savage conquest and exploitation combined with corrupt and inefficient administration. Prescott, in his *Conquest of Peru,* tells us that "men of base qualities which might have passed unnoticed in private life, were made conspicuous . . . by sudden elevation to power; as the sunshine which

operates kindly on a generous soil and stimulates it to production, calls forth from the unwholesome marsh only foul and pestilent vapours." In the rush to get the gold of the Mexican and Peruvian Empires, however, much exploration was done, and for that we must be thankful. Now, after the first voyage of Columbus, Ferdinand and Isabella made a kind of West Indian Office and put a certain Bishop Fonseca in charge of this public department—with results that have been duplicated in other countries. Fonseca sent a soldier, Rodrigo de Bastidias, to explore the Spanish Main, and Vasco Nunez de Balboa sailed with Bastidias. Fonseca also sent a soldier called Ojeda to Darien and settlers were put there, abandoned and relieved by Pizarro in 1509. Among these refugees was Balboa. He was a bold and enterprising man, a good soldier and yet a wise and humane administrator. He was also an explorer. Among the crowd of Spanish adventurers who followed Columbus to the West Indies there were very few indeed with the sterling qualities of Balboa. He became Governor of Darien and commanded an expedition that crossed the Isthmus, ascending the inland Sierra. Before actually reaching this summit of the "Peak in Darien," Balboa halted his men, went on alone, and then, on 25th September 1513, he looked down on the Pacific Ocean, extending indefinitely away to the south. His followers built a cross on the spot and then they descended the slope towards the sea, when one of them, Alonzo Martin, waded into the water as far as he could go and took formal possession of the "Sea of the South" in the name of Spain. Long before that time Indian peoples from the valley of the Ganges, Phœnician sailor-traders from the Red Sea, and Arab merchants had entered the Pacific Ocean from the Straits of Malacca, or over the Malay Peninsula. The brothers Polo and Marco, their nephew, had crossed the whole Asiatic continent and seen the South China Sea. But now European explorers had crossed the Atlantic Ocean and the American Continent to touch the Pacific Ocean, and in a few years more Spanish ships were to sail in its waters.

Magellan's Strait. Between 1503 and 1519 various Spanish and Portuguese expeditions made their way down the coast of Brazil and towards the south of America in search of the opening that was to take them east. It is said that Gonzalo Coelho in 1503 reached the coast of Patagonia and actually entered the Straits; it is fairly certain that there were reports that it existed and that Magellan acted upon these in choosing the route for his expedition—anyhow,

in 1519, he did sail with a squadron of five ships to find the way west to India.

Fernao de Magalhaes was a Portuguese of noble family born in 1480. He was a soldier and had served with the missions to the Far East of d'Almeida and Albuquerque in the conquest and exploitation of the countries and islands of the Indian Ocean that had been visited by the Portuguese, and he was naturally anxious to do something by himself. Like Columbus he offered his services to his own sovereign, but received no encouragement, and so, in 1516, he denaturalized himself and became a Spanish subject. He conceived the idea of organizing an expedition to go south along the American Atlantic coast and search for the strait that led through into Balboa's "Sea of the South," acting, it is fairly certain, on vague reports that such a passage existed and had actually been entered. Ultimately he was successful and in September of 1519 Magellan's expedition, perhaps the most famous and notable of any that has yet been made, left San Lucan in Spain for its three years' voyage of world-circumnavigation.

The squadron consisted of five vessels, the tonnage of which varied from 75 to 120. Of these ships the *San Antonio* deserted in the Straits and returned to Spain in 1520. The *Concepcion* became unseaworthy, her stores and men were divided among the other vessels and she was burned—this was at Bohol in the Philippine Islands. The *Santiago* was lost off the coast of Patagonia before entering the Straits. The *Trinidad* was sent on a voyage of exploration from the Molucca Islands to Panama, but she never reached her destination. There was much enmity between the Portuguese of the Moluccas and Magellan's expedition—the leader being hated because of his denationalization—and so the ship was arrested and her crew were treated with great inhumanity: in the end only four men reached home. The *Victoria* alone completed the voyage of circumnavigation. Magellan himself was a man of harsh and arbitrary temper, capable of acting with great cruelty: there seems to be little doubt that he was much disliked, and the tragedy that, all the time, clung to his adventure must be attributed, in part at all events, to the personality of the leader.

In all between 270 and 280 men left Spain with Magellan; 18 came back to Seville with the *Victoria*; 13 were sent home from Cuba; so that, with the 4 men of the *Trinidad*, 35, in all, survived the expedition. Magellan himself was killed in a fight with the

natives on the Island of Cebu (Zebu) in the Philippine Archipelago.

The itinerary of the *Victoria* is shown by the dotted line in Fig. 14. The squadron arrived at the entrance to the Straits on 21st October 1520. On 22nd November they entered the waters of the Pacific Ocean, the first modern vessels to navigate that sea and the first of all to pass through between Patagonia and Tierra del Fuego. Then for sixty days they sailed across the Pacific, finding "everywhere nothing but the sea: always the sea." They arrived at St. Paul, in the Low Archipelago, on 24th January 1521. On 6th March they came to the Ladrone Islands and on 16th March they made the Philippines. There, as we have seen, Magellan was killed while he stayed to make his colony and assist the Sultan of Cebu. On 8th October 1521 the *Victoria* and *Trinidad* were at the Moluccas, by this time in the hands of the Portuguese, and, as we have seen, the *Trinidad* was lost. The *Victoria* alone completed the voyage, leaving for home on 18th December 1521 and arriving in Spain on 8th April 1522, having sailed round the world for the first time in maritime history.

All the oceans had now been crossed. Vasco da Gama led the way by crossing the Indian Ocean from the Cape of Good Hope to Calicut in India, Columbus crossed the Atlantic from Portugal to the Bahama Islands, and Magellan crossed the Pacific from the Straits to the Philippine Islands. The full extent of the oceans was now for the first time disclosed to geographical science.

The Habitable World in 1529

This is a convenient place to pause and consider the state of geographical knowledge after the great expeditions. All three great oceans had been traversed with the result that the magnitude of the land surface had been enormously reduced. Both sides of the Atlantic Ocean were very well known and though little was known as to the details of the Pacific coasts yet their general trend had been established. The Indian oceanic coasts were best known, and now that the approximate east-and-west dimension of that ocean and the north-and-south dimension of Africa had been found out the land features of the eastern world were made more like those of our modern maps. For the first time a "mappa mundi" differed essentially from that based on the work of Eratosthenes twelve centuries prior to the voyage of Magellan.

In 1529 Diego Ribero, a distinguished cosmographer, made a

world-map which is represented, in outline, in Fig. 14. There are now two great land regions isolated by three oceans. Europe, Asia and Africa make up one land region and North and South America another. The Atlantic Ocean separates the two land-masses on the west and the Pacific Ocean separates them on the east. The Atlantic and Pacific are continuous north and south with polar seas—such appears to be suggested in Ribero's map, though, as we shall see in Chapter IV, most people in the sixteenth century imagined land round both Poles of the earth, for Magellan's strait was believed to separate America from what they thought to be a great southern continent, and the search for a familiar strait on the north indicates that they visualized also a northern land-mass. The Indian Ocean differed essentially from the other two since it had no northern outlet. In a way it was regarded as what we should call an immense oceanic bight.

The Limits of Human Distribution. The ancient geographers, we have seen, regarded the temperate zones as the only regions inhabitable by man. The torrid and frigid zones were not habitable—the former because of their intolerable heat and the latter because they were intolerably cold. Now the discoveries of the tropical regions of Africa and Central America showed that the torrid zone could harbour an abundant savage population and that it was also capable of being colonized by European peoples. Also there were human beings even in the lands adjoining the frigid zones. Even if Magellan did not demonstrate the existence of savages in his Tierra del Fuego, the early voyagers to Greenland and Labrador had found men there. Now we know that, of all animals, man is the most adaptable, not only physically as animals (such as the ants) are, but mainly by reason of his high degree of intelligence which has enabled him to meet naturally inclement conditions by making use of tools (in the widest sense, for all artifacts, such as clothing, shelters, weapons, etc., are "tools"). Therefore we know that men can now exist far within the ancient limits of the Arctic and Antarctic Circles.

The essential condition for animal life is water—sea in the unfrozen state. Therefore wherever the sea is not permanently covered with ice we find, in the north, the Eskimo, and the absence of man in the frozen Antarctic is due, in all probability, to the isolation of that continent from Asia, America and Africa *before* man had evolved.

Still it is interesting to note that the ancient conception of the

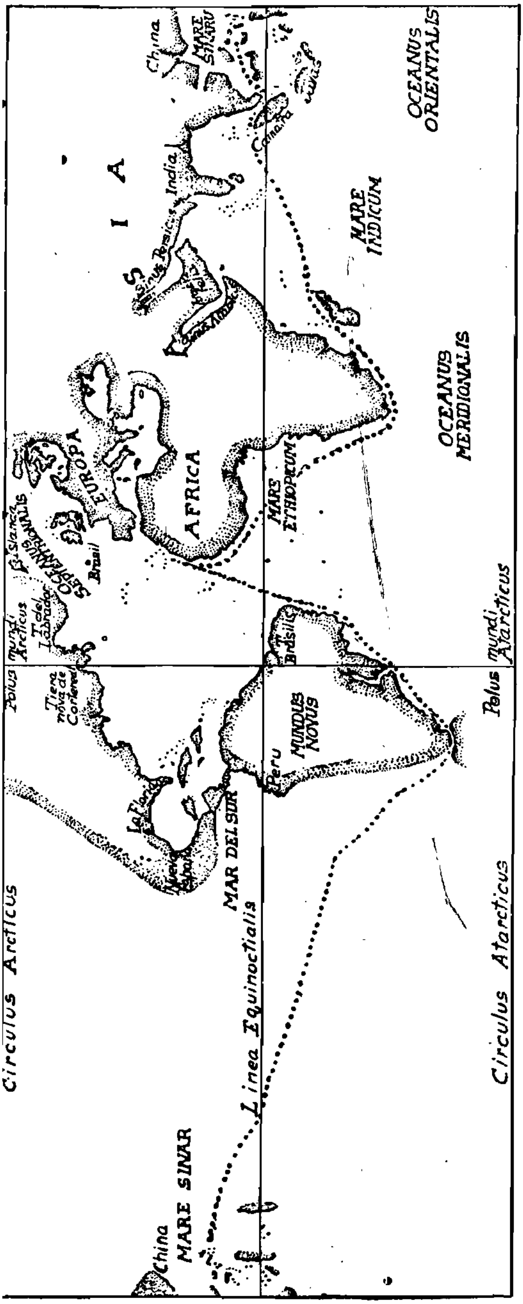


FIG. 14.—Map of the World as known in 1529.
From the map made by Diego Ribero.

uninhabitable circumpolar zones has been maintained by modern geographical discovery even though the sterile regions are now restricted to far within the two circles. On the surface of the Paleocrystic Sea of the Far North and on the high Antarctic ice-cap human life (except that of the few explorers who have ventured there) does not exist.

The Political World in 1529

These great discoveries that are summarized in the map of 1529 have, from our point of view, interest that is mainly scientific, but our study would be a very partial one if we were entirely to overlook the political consequences of the finding of the new continents and oceans. We have seen that the " economic motive " was a powerful stimulus to geographical adventure and such it continued to be throughout the next three centuries. A brief retrospect of the political world in 1529 is, therefore, not out of place here.

The Hapsburg Empire. The one unifying influence in the world between the times of the fall of the Roman Empire and the fifteenth century had been the Church, acting directly or, from the time of Charlemagne, through the Holy Roman Emperor. Charles V succeeded in 1520. He held the thrones of Spain, Naples and Sicily, and Sardinia, and he held the Netherlands. He was Emperor. In his time he was the bulwark of Europe against the Turks, who, in 1529, were even besieging Vienna itself. Twenty-seven years were still to pass before Charles (like another Emperor, Diocletian), weary of world-power, was to seek refuge in abdication. The time was to come when the Netherlands were to revolt against Philip, the son of Charles, to obtain independence and, with the assistance of England, to challenge and supplant the monopoly of commerce set up in the Far East by Portugal.

England was then ruled by Henry VIII. She had been, and for long continued to be, a country with a stationary population. She had a small trade overseas with Bordeaux and Cadiz, from which ports her vessels brought wines and other commodities. Her ships traded also with Antwerp and the Scheldt, carrying the wool which was the main English export. They brought back spices, perfumes, rice, cotton, indigo and gems which had come from India ; fabrics from Persia and Turkey ; sugar, metals, pearls, fruits, etc., from the New World. They brought furs, tallow, hemp, flax and timber from Russia. The overseas trade was small : later (in the time of

Elizabeth) it amounted only to between two and three millions of pounds annually. But, even then, there was a fishing fleet which went annually to Iceland to catch cod and the locally conducted fisheries were, for those times, big ones. This prosperous fishing industry was (in Elizabeth's time) to become a decadent one because of the growth of a kind of patriotic, piratical adventuring. Henry began to build his navy soon after he succeeded and, in the year 1530, a certain Mr. William Hawkins had begun to poach on Portuguese preserves by capturing African slaves in Guinea and taking them to Brazil. This curious fact illustrates the effect of the Spanish and Portuguese trade policy to which we shall refer presently.

Venice was, and long continued to be, the great commercial and trading European city. Even then control of industry by financial interests was an important factor in economics. In the reign of Charles V it was divided between Venice and the famous German business house of the Fuggers. It is a curious fact that, from 1511 onwards, the great Portuguese exploring voyages were financed by the bankers of Rome, Florence and Lombardy.

Spain. In the reign of Ferdinand and Isabella Spain was a poor country. After generations of fighting she had expelled the Moors and, as the result of long political persecution, she had also thrust out the Jews. Then, a country with a small population, without industries or riches and with a commonalty oppressed by the dead hand of the Church and by the privileges of an old nobility, she acquired a great Empire. Within a generation after the return of Columbus from his first voyage the Spanish American dominions included the Islands of the West Indies, Darien, the Spanish Main, all the coastal parts of North America up to California on the west and Carolina on the east, and all South America except Brazil, which had been found and colonized by the Portuguese. Before 1529 Cortez had conquered Mexico, after campaigns of infamies, and in 1530 Pizarro was setting out to do the same in Peru.

The Spanish Policy in America. The ideals of the Spanish monarchs and their advisers were admirable, but their realization is one of the greatest examples of political failure that world-history gives us. The effect has been described as that of the establishment of an "old society in a new country." It transferred to the American colonies the dead hand of the Church on the land, the privileges of an old and proud nobility and the procrastinating and routine methods of a State officialism. As if all that was not enough it

burdened the colonies with the dead weight of a mistaken economic policy which, in spite of its obviousness, was to prove to be a fatal one.

This policy was that of trading monopoly. The trade with the daughter-colonies was reserved for the mother-country. The former were prohibited from exporting anything which might be produced in Spain : all that they might trade with were their raw materials and articles, or products, which could not be found or manufactured in the home-country. The correlative to this policy was, of course, the production in Spain of all the commodities required by the colonies : also it assumed the existence of sufficient carrying vessels for the trade that was to be expected—and of naval power competent for the protection of such a trade against foreign aggression in time of war, or of piracy in time of peace. Now plenty of politicians still believe in and advocate such a policy of exclusivism and it may be good or bad according to circumstances, and relative to our criterion of what "good" or "bad" connote in the life of a nation. But in this case of Spanish commerce in the sixteenth century it was thoroughly bad because the mother-country could not (because of its policy with regard to the Jews) produce the commodities required by the colonies nor could it protect whatever colonial trade it endeavoured to establish. The results were such interesting occurrences as the adventures of Mr. William Hawkins; the private trading of the French, Dutch and English with the Spanish Colonies, the buccaneering of the sixteenth and seventeenth centuries by vessels of the same nationalities, and the privateering of the Elizabethan "sea-dogs." One must not forget, however, the extraordinary bitterness with which all this illicit trading was carried on—an animosity which had its main root in the religious cleavages of the period of Charles V.

Another reason for the failure of Spanish colonial policy was also an economic one. Then (just as with many statesmen of our own time) wealth was confused with money and it was prohibited to export gold; but, on the other hand, all efforts to import and hoard gold were regarded as beneficial to the country. Wealth, of course, consists of the accumulation of commodities—things which have been produced, or made, or rendered accessible for the use of man and which can form the materials of commerce. Such wealth existed, in Spain, only to a very limited extent, and it could not be replaced by the gold that was produced in the Peruvian mines and shipped to Spain.

In spite of her failure to establish a great colonial trade the colonization of America that began after Columbus has not been unsuccessful. The population of Spanish America is still largely Indian, and it cannot be denied that the curious mixture of stocks that we find in the southern continent has acquired many of the characteristics of the mother-country. If, then, the assimilation of a huge alien population, the general adoption of a language and the acquirement, by these subject peoples, of some prominent characters of their conquerors, are the criteria of a successful colonization, we must regard the Spaniards as having succeeded in colonizing Southern America and Mexico.

Portugal. Vasco da Gama returned from India in 1498. In 1505 d'Almeida left the Tagus and went east as the first Portuguese Viceroy of India. He fought the "Moors," that is, the Arabs, at Mombasa, reached Malabar and returned home, *viâ* the east of Madagascar, in 1506. After him went Albuquerque and the result was the passage of the Straits of Malacca. Then the Portuguese took the Moluccas—the famous Spice Islands, with their riches of cloves, pepper, nutmegs, etc. Thus their empire extended along both coasts of Africa, to India and to the known islands of the East Indies, stopping at Borneo. Very soon there was a lucrative trade between Portugal and the Far East, *viâ* the Cape of Good Hope. And then, just a few years later, Magellan found his Strait; crossed the Pacific for sixty days until he came to the Low Archipelago; went on for other thirty days and came to the islands which we now call the Philippines, after the name of the son of Magellan's adopted king. His successor in command of the expedition went on still until he came to the same spice islands which Albuquerque had found by going south and east round the Cape of Good Hope.

The Pope's Line. "Spheres of influence" had therefore to be marked out by the respective governments, and these negotiations led to the readjustment of the famous "Papal Line." Now the student must note that never in the history of the world has any independent State allowed the subjects of other States to trade with its own subjects without restrictions of some kind--thus we have the complex modern systems of tariffs and customs and commercial agreements between governments. Every maritime State holds jurisdiction over a zone of sea adjacent to its dominions in just the same degree as it has jurisdiction over the land. The width of this zone of territorial sea is held by international law to be equal to the

range of cannon mounted on the shore and firing straight out to sea: the legal phrase was " Terrae dominum finitur ubi finitur vis armorum." But at the beginning of the nineteenth century the width of the zone of territorial sea was fixed at three nautical miles from low-water marks, and this is the distance in most maritime countries. Ships of war do not enter the territorial waters of other States than their own, except ceremonially, or by invitation, or under stress of weather, and the vessels of two States which are at war with each other may not engage in belligerent operations when within the territorial waters of a third State. In Britain this zone of neutrality is even held to include great bays, the waters of which lie between two prominent headlands—the Bristol Channel, for instance, between St. David's Head and Land's End. Such waters are said to lie within the jaws of the land—" inter fauces terrae "—and they belong to the land in so far as questions of neutrality are concerned. In Scotland these great bays are also exclusive fishery districts, even though the greater part of their area may lie outside the strict three-mile limit.

Outside the waters of the great bays (" the King's Chambers ") and the three-mile limit off open coast is the " High Sea," and here no State can exercise any exclusive right: the High Sea is common to all the peoples of the world and none can arrogate it to its own use. There was a curious custom, with regard to English and British ships, which persisted from the time of King John until just after the Battle of Trafalgar—this was called the " Naval Salute " and it consisted in all vessels whatever lowering their topsails and striking their flags when they met an English ship of war, whether in an English harbour, in a foreign harbour, or on the High Sea. The custom of the naval salute originated at a time when the English Channel was infested with piratical vessels and when it was necessary to examine suspicious craft: it persisted because of the English susceptibility, at all times, to anything that tended to diminish sea-power.

The theory of the King's Chambers, the territorial waters and the High Seas was worked out mainly by the Dutch international lawyers in the seventeenth century, when the United Provinces were resisting the maritime monopolies of which we are just about to speak. The theory was given practical effect by the Elizabethan sailor-adventurers of the Elizabethan period and, in the early years of the nineteenth century, it became embodied in law mainly by the decisions

of the British Admiralty Courts. A large part of naval history—even that of the European War of 1914–1918—is made up of the controversies, negotiations, treaties and actual fighting in relation to these questions of naval and maritime-commercial privilege and monopoly. In order to understand these controversies and conflicts we must go back to the immediate results of the voyages of Columbus and Magellan.

In 1493, immediately after the return of Columbus from his first voyage, Spain and Portugal proceeded to share out the new lands that they had discovered between them—rather prematurely as it turned out. Spain had found what they regarded as lands rich in gold in the West, and Portugal had found the islands rich in spices in the East. In addition to these positively known resources there were sure to be others, and these had to be divided.

So, on the 4th May 1493, the Pope, Alexander VI, had a globe brought to him and then, with his own hands, and in the presence of his Cardinals, he traced a line running down the Atlantic Ocean from the North to the South Pole and distant a hundred leagues to the west of the Azores, or the Cape Verde Islands. (These were supposed to be on the same meridian, so inaccurate were the methods of determining longitude in those days.) All lands to the west of this line were to go to Spain, with all new lands that they might discover there. All lands to the east of the line discovered, or to be discovered, were to go to Portugal. The privileges that were thus allocated to the rival kingdoms included the exploitation of the resources of the new lands; the dominion over the peoples resident there; the monopoly of trade with these lands and the monopoly of navigation in the seas adjacent to them.

This was quite in the spirit of the period. While at the height of her power Venice arrogated to herself the privilege of navigation in the Adriatic, Genoa claimed a similar right as regards the Ligurian Sea. Denmark claimed the exclusive rights of navigation in the Baltic. There was nothing unfamiliar to the lawyers of the sixteenth century in such pretensions, but never before in the history of the world had any Empire sought to monopolise the ocean.

Very soon, however, the line had to be adjusted. Portugal protested against the effect of the Papal Bull. The extreme north-east part of the South American continent had not then been explored, but the Portuguese argued that the proximity of the line to the Old World was likely to deprive them of lands that they might yet find.

So, on 7th June 1494, after renewed negotiation, the line was shifted to a distance of 370 leagues to the west of the Azores. The new World to the west of this belonged to the Spanish, while the new parts of the Old World that lay to the east belonged to the Portuguese. With these privileges of trade and navigation went that of converting the natives of the new lands to the religion of the old one.

Now the conception of the spherical earth was about to triumph by its appeal not only to the reasoning of the cosmographer but also to national cupidity. Vasco da Gama and d'Almeida and Albuquerque had found the Islands of the Moluccas by sailing to the east, while Magellan had also discovered them by sailing to the west. The envied Spice Islands lay both to the east and west of the Pope's Line. So again the spheres of influence were readjusted: in 1529, after the return of the survivors of Magellan's expedition, negotiations were undertaken and the Moluccas were ceded to Portugal for the sum of 350,000 gold ducats. They remained Portuguese until the Dutch had challenged the maritime pretensions of the Portuguese and the English had become able to break the monopolies of the Dutch.

CHAPTER IV

THE CIRCUMPOLAR REGIONS

By the middle of the sixteenth century geographers were able to make maps of the world that showed all its great, natural features much as our own maps do. They knew of the Old World land-mass with its three regions : Europe, Asia and Africa. They knew also of the New World with its northern and southern continents. There were the three great water regions : Atlantic, Indian and Pacific Oceans. Local topography was still to be studied, but that had to wait for the perfection of surveying instruments rather than for the means of travelling, which were not much inferior (so far as mere exploration is concerned) to our own.

But with regard to the circumpolar regions there were only the very vaguest ideas. The maps show that men, in the sixteenth century, had a clear and accurate notion of the general balance of land and sea on the face of the earth with the exceptions of the extreme north and south. They conceived a great southern continent not far away from the Cape of Good Hope and lying immediately to the south of Magellan's Strait : this notion having, apparently, come down from Ptolemy's map. On the north the maps seem to indicate that the European and American land extended indefinitely towards the Pole, but that there were straits leading west and east to the Pacific Ocean. Why they were so sure about the existence of these straits we do not know—perhaps it was just because they felt that there *ought to be* straits—anyhow from this time onwards two ideas were to dominate plans of exploration : (1) the search for the southern continent and (2) the search for the north-west and north-east passages to India *viâ* the Pacific Ocean. Now just because the existence of such passages would have been of immense practical value to the North European traders it happens that it was the British sailors who mainly sought for it. We know now that there are, indeed, both north-west and north-east passages from the Atlantic Ocean to the Far East, but we know also that these

routes are commercially impracticable. It required, however, three centuries of exploration before that knowledge was attained and, in the meantime, the motive of a sea-route for trade to the East was combined with that of the search for the North Pole.' Southern exploration had, apparently, no other motive than scientific curiosity, for there did not appear to be countries to the south of the two Capes that were worthy of being exploited.

In this chapter we shall briefly summarize the main voyages of exploration that were made into the north and south circumpolar regions, and then we shall deal with the physical geography of those parts of the world in the light of the results of modern oceanographical research.

The Far North

We have seen that the Norsemen had, sometime during the eleventh, twelfth, or thirteenth centuries, crossed the Atlantic and established themselves in Greenland, Newfoundland, and possibly in the region that we call the United States of America. But beyond the stories of the Norse Sagas there are no records of the results of these early transatlantic voyages and certainly no maps. Their interest is antiquarian and also physical, for there are reasons for believing that seagoing round Iceland and Greenland was an easier matter in the eleventh to the fifteenth centuries than it is now.

The Zeno Map. About the middle of the sixteenth century a certain noble Venetian called Nicolo Zeno examined the papers in the possession of his family and came across remains of records and maps indicating that, in the fourteenth century, his ancestors had voyaged in far northern regions. Nicolo reconstructed these remains and made a map which was published in 1558 and which appears to represent the first attempts that were made at the investigation of a north-west passage to India. Being a reconstruction of a hypothetical earlier document we cannot attach much importance to the Zeno Map, yet it shows what must have been the ideas of the geography of the Far North that were current before the Cabots made the first of the modern voyages of polar exploration.

The Zeno Map is represented by our Fig. 15. It shows continuous land to the north of the Atlantic Ocean, a great peninsula called Engroneland being connected with Norway. In the bight thus

formed lie several islands, one of which is certainly Iceland, while the others (Icaria, Frisland, Estland, etc.) are probably based on the discovery of the Faeroe Isles by several investigators and at different times, so that the accounts became very confused. To the south-east, however, are lands called Estotiland and Drogeo, and these are, very probably, the results of early discoveries of Newfoundland or Nova Scotia. Further it is interesting to note that between Engroneland (Greenland) and Estotiland there lies a strait, and this

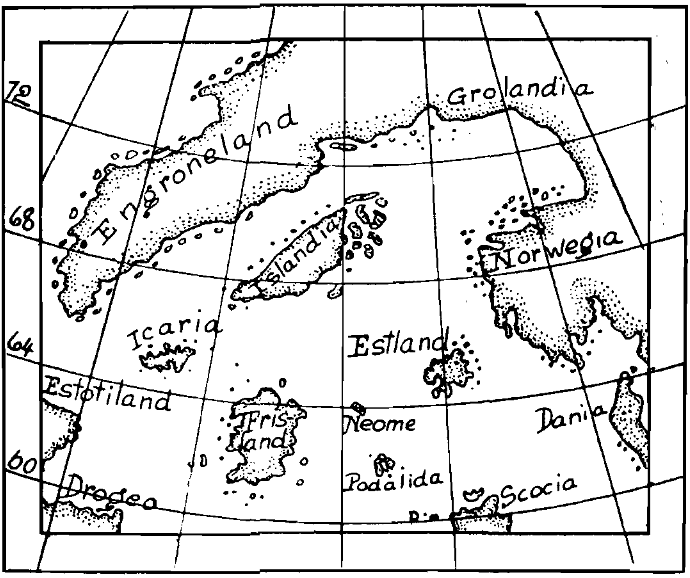


Fig. 15.—The Zeno Map. Date about 1380.

is the feature of the Zeno Map that had significance for the old Venetian geographer.

The Voyage of Cabot. It is known that Columbus, in the years when he was unsuccessfully trying to persuade the Portuguese and Spanish courts to equip his transatlantic venture, endeavoured also to interest Henry VII of England in his ideas. Henry, as we know, would have nothing to do with the project, but when it was reported that Columbus *was* successful English aspirations awoke. Henry then gave a " patent " to John Cabot, a Venetian naturalized in Bristol, to exploit any lands he might discover on the other side of the North Atlantic, and in 1497 the Cabots made their first voyage of exploration and found land which they called " Prima Vista "

and which was probably Cape Breton Island. They also found the Islands of Bacalhaos (which means codfish)—that is, our Newfoundland, which soon became famous for its cod fisheries. They found also a wide estuary, which is the Gulf of St. Lawrence, and north of this is the land called Labrador by us.

Portuguese Voyages of the Sixteenth Century. Two brothers, Gaspar and Miguel Cortereal, appear to have made several voyages into the Far North, discovering land to the north of Newfoundland which is shown on Ribero's map (Fig. 14) and is called there Tierra Nova de Cortereal. They also found Bacalhaos, and it would appear that they had even penetrated into Hudson's Bay. The chronology (and indeed all the details) of these voyages are very confused and it would not be useful to go into them. Anyhow a Portuguese sailor called Estavoa da Gama sailed in 1502 in search of the Cortereals, who had been lost, and he also explored the coast of Newfoundland. Thus a good deal of voyaging in the North Atlantic region had been carried on before the English ventures of the Elizabethan period, and it is interesting to see that this early exploration was the work of the Venetians and Portuguese. We cannot deal with it here, and all we have to note is the general state of knowledge prior to the famous voyages of old John Davis and his immediate successors in English geographical discovery. That knowledge we may regard as summed up in the map (Fig. 16) contained in an atlas prepared by Ortelius and published in 1570.

Here we see the North Atlantic lands, as we know them, rather crowded together and all a good deal out of place, but still suggesting the relationships that exist. There is sea (the *Mare Congelatum* or Frozen Sea) to the north of Norway. Greenland is now an island and Estotiland has all the appearance of having been regarded as part of a western mainland (America). Drogeo is an island. Iceland and Frisland are both shown, but we have also the Faeroe Isles (Farre Islands). Between Greenland and the mainland is a strait that must have been supposed to lead into the Eastern Ocean, and this is the most significant feature of the map. But we see also that land is supposed to exist beyond Greenland and tending in the direction of the Pole, and that Pygmies are said to exist here. Probably the Eskimos, or Laps, had by that time been seen. The map of Ortelius, then, represents the state of geographical knowledge before the beginning of the modern English voyages.

The English Voyages: The North-West Passage

These began, of course, with the voyage of Cabot towards the north-west coast of America. In 1551, Sebastian Cabot became Governor of the "Company of Merchant Adventurers," and this corporation endeavoured (and succeeded to a certain extent) in developing a trade with Muscovy (Russia) *viâ* the White and Kara Seas. It sent out several expeditions towards the east which added

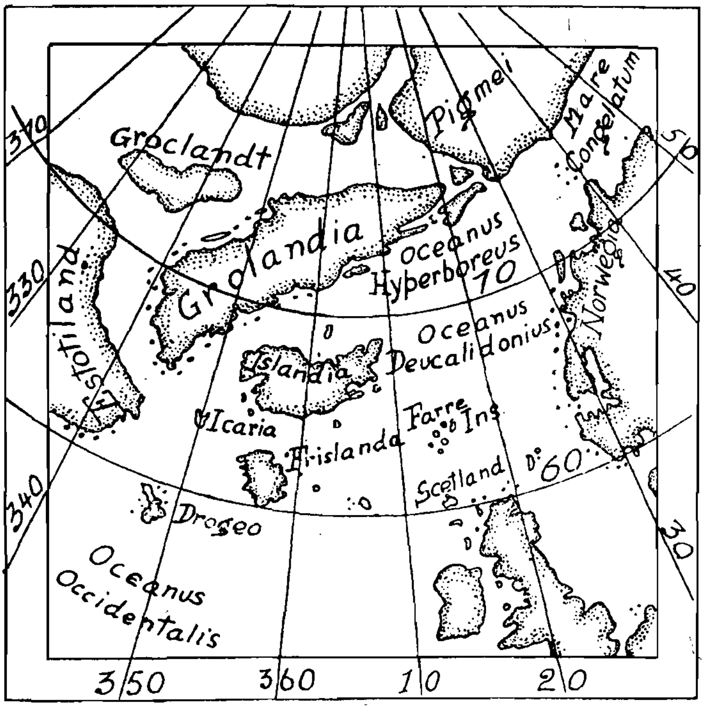


Fig. 16.—Arctic Regions from Atlas of Ortelius, 1570.

to existing knowledge of the North European coastal seas. Then in 1576 Martin Frobisher made the first voyage deliberately in search of the north-western passage, and in the course of this an apparent discovery of gold was made which led to two further voyages by Frobisher. These were all in the direction of Greenland.

John Davis and his Strait. John Davis was a west-country sailor who was selected by some London merchants to search for the north-west passage. He made three memorable voyages into the Arctic regions, and it was the results of these on which all subsequent

expeditions were based. He was a scientific man as well as a sailor, writing a book on navigation and inventing new methods and instruments. He was also a literary man, and his descriptions of the Arctic Seas gave his countrymen, for the first time, vivid notions of the conditions in the Far North.

Davis made three voyages to Greenland, the first being in 1585 when he left Dartmouth with two little vessels, the *Sunshine* and *Moonshine,* of 50 and 35 tons respectively. Davis's own vessel, the *Sunshine,* was manned by 5 officers, 11 seamen, 4 musicians and a boy. They reached the east coast of Greenland and approached the land with a calm sea, a dense mist and " a mighty great roaring " in their ears. Then, when the fog lifted, they saw " Greenland's icy mountains " with the huge, Arctic ice-pack between them and the land. The " mighty great roaring " was caused by the ice-floes drifting down from the north, grinding on each other, up-ending, overriding and battering on the shallow sea bottom. Davis's own description has often been quoted as a piece of quaint, forcible English : " The lothsome viewe of the shore and the yrksome noyse of the yce was such that it bred strange conceipts among us, so that we supposed the place to be wast and voyd of any sencible or vegetable creatures whereupon I called the same Desolation."

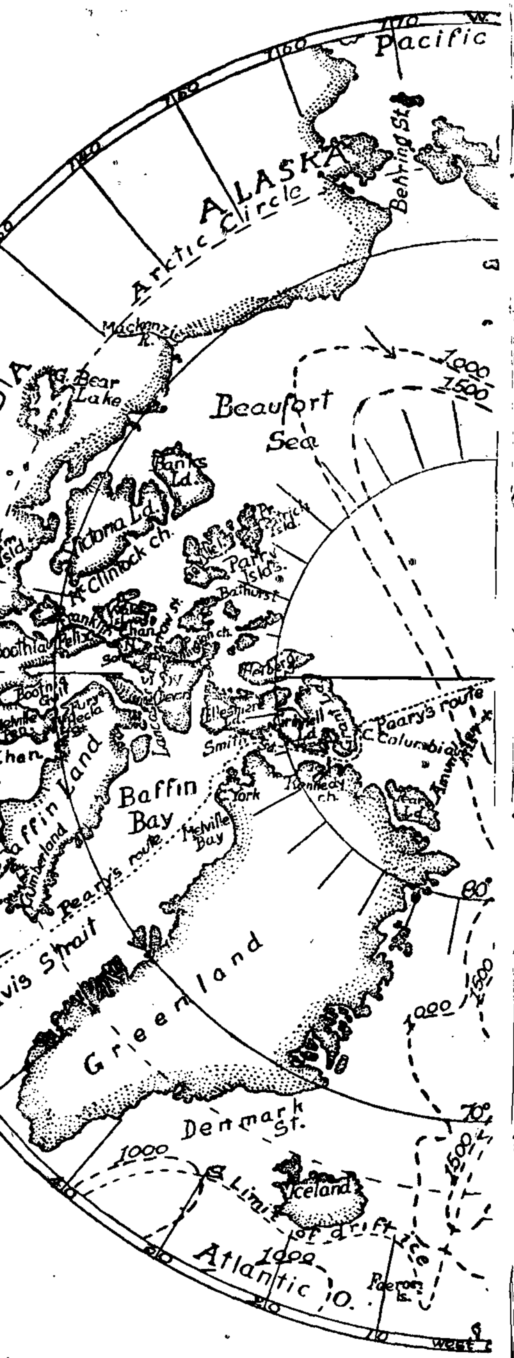
Then they rounded Cape Farewell and, still penetrating the ice-pack, they made their way up what has since been called Davis Strait, undergoing unanticipated privations, which they met sensibly and bravely. The rations of the men were increased to 4 lb. of bread and 12 quarts of ale per daily mess of five persons—and in such conditions they made progress. On this first voyage they touched the Arctic Circle off the coast of Baffin Land, and then, creeping south past the " Cape of God's Mercy," they came home.

Davis made two further voyages, in 1586 and 1587. He was the first English sailor to visit Greenland after its early colonization by the Norse and the extinction of these settlers by the Eskimo. He discovered and explored the channel between Greenland and Baffin Land, and he found four apparent passages, any one of which might have been the strait leading to the Far East. One of these passages led north past a prominent headland on the Greenland coast which Davis called " Sanderson, his Hope," after the name of one of his London supporters : this was the way towards the channels afterwards called Lancaster and Smith Sounds—the routes to the north-west passage and the North Pole respectively. He found an inlet

on the west of his strait that he called " The Furious Overfall " (an overfall is the turbulent seaway caused by strong streams striking against rocks on the bottom, rising up to the surface and then boiling over, so to speak). The " Furious Overfall " was the entrance into Hudson Bay. He returned to England in time to command a little ship called *the Black Dog* in the great fight against the Spanish Armada.

Baffin and Hudson Bays. Thus the entrance to the Arctic regions between Greenland and Baffin Land became known and charted in a regular way and the next voyages that were made followed up the work of Davis. The strait became extended out into the wide inlet called Baffin Bay, and the Furious Overfall proved to be the opening into an immense, landlocked sea. In 1610–11 Henry Hudson and his son went north (and " west ") in a little vessel called the *Discovery*—the first of the honourable series of exploring ships that have borne that name. She explored a large part of the bay that bears Hudson's name on our maps, wintered there, and then, with serious discontent aboard, broke out of winter quarters. The crew mutinied and Hudson, with his son Jack, Thomas Woodhouse " the mathematician," and seven men, were turned adrift in an open boat and heard of no more. About a month afterwards the mutineers were surprised by the Eskimo and most of them were killed. The *Discovery* returned to England.

Hudson was followed by Thomas Button, with the *Heartsease* ; Robert Bylot, with the *Discovery* ; William Baffin and Bylot, with the *Patience* and *Discovery* ; Luke Fox, with the *Charles* (backed by Mr. Henry Briggs, the mathematician), and others, of course ; the record is a long one. All these voyages occurred in the seventeenth century, and their result was to make out most of the topography of Davis Strait, Baffin Bay and Hudson Bay. Baffin discovered the two channels that led out from the top of Baffin Bay, beyond Davis's " Sanderson's Hope " : these were Lancaster Sound and Smith Sound and it was through them that most of the ships that, afterwards, went in search of the north-west passage and the Pole were to sail. Luke Fox discovered that Hudson Bay trended away to the north, in a wide strait which was afterwards called Fox Channel, but no way was found out of the bay. Not until 1822 did Parry discover the way out, through " Hecla and Fury " Strait (between Melville Peninsula and Baffin Land), but this was found to be impracticable as a rule. The seventeenth century ended, then,



Arctic Regions : Western Hemisphere.
ntours and the numbers placed on them represent fathoms.

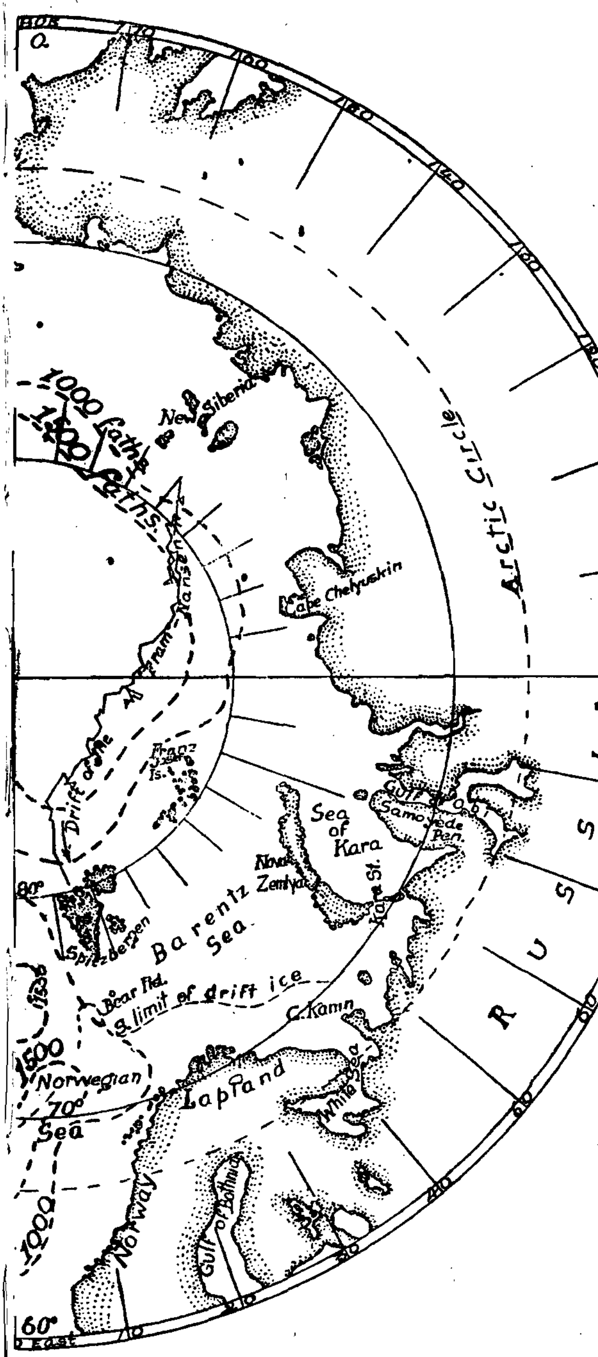


FIG. 18.—The Arctic Regions Eastern Hemispher
The broken lines with numbers are the depth-contours, the numbers rep

with the knowledge of Greenland, Davis Strait and Baffin Bay, and Hudson Bay—no more than the approaches into the circumpolar sea. The other approach, *viâ* Spitzbergen, had hardly been attempted.

The Government Rewards. So important did a knowledge of the Arctic regions appear to be that, in 1745, 1776 and 1818, a series of rewards were offered for the results of successful exploration in this part of the world. In 1745 the British Admiralty offered £10,000 for the discovery of the north-west passage to India. (This was paid to M'Clure and the crew of the *Investigator* in respect of their voyage of 1850–2. See p. 113.) In 1766 a reward of £5,000 was offered to the ship that would reach the latitude of 89° N. (this was not claimed). In 1818 a reward of £5,000 was offered to the ship that would reach the Pole (this also was not claimed), and another reward of £5,000 for the crossing of the meridian of 110° W. from Greenwich, within the latitudes of the Arctic regions. (This was paid to Parry and the crews of the *Hecla* and *Griper* in respect of the voyage of 1819.) In 1818 a graduated series of rewards—£1,000, £2,000, £3,000, £4,000, £5,000—were offered for the following achievements respectively, attaining the latitudes of 83°, 85°, 87°, 88° and 90°. These were subsequently withdrawn, but £5,000 was given to M'Clintock and the crew of the *Fox*, who, in their search for the remains of the lost Franklin Expedition, surveyed the regions involved in the north-west passage.

The State of Knowledge in the Eighteenth Century. The English sailors had thus explored Davis Strait, Baffin Bay and Hudson Bay, but they had not found navigable passages out from those seas—all that was indicated was that Baffin Bay probably led, by the north, into a polar sea and, on the west, towards the North American Arctic Sea and *viâ* this to Behring Strait. Most of the east coast of Greenland was known and Spitzbergen had been discovered and, indeed, had long been the headquarters of a whale-fishery. Almost the entire north European and Siberian coastlines as far east as Behring Strait were known—though they have not been traversed in their entirety by any one vessel. Novaya Zemyla and the New Siberian Islands were partially known. Practically all the North American coast between Baffin Bay and Behring Strait was unknown and the north coast of Greenland was quite unknown. These details of our knowledge of the polar regions are represented in Fig. 19, which is a reproduction, in outline, of a chart

prepared by Sir John Barrow, who was Secretary to the British Admiralty in 1818. Now this was the state of knowledge when the Admiralty rewards were offered and just before the beginning of that remarkable series of voyages to the north and south circumpolar regions that occupied British and American explorers throughout the greater part of the nineteenth century.

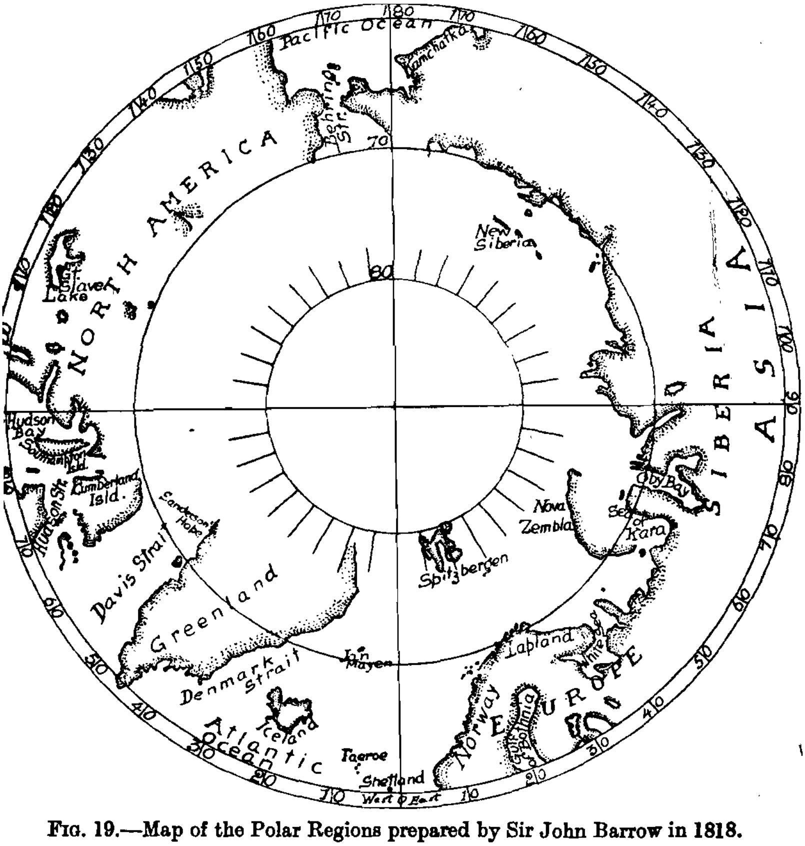


Fig. 19.—Map of the Polar Regions prepared by Sir John Barrow in 1818.

Geography of the North Polar Region

Now let us look at a modern chart (Figs. 17 and 18). We see that practically the entire area we are considering is contained within the Arctic Circle. The parallel of 70° N. roughly corresponds with the eastern land margin of our region so that Lapland, the Russian and the Siberian coasts bound the Arctic Ocean throughout rather

more than 180° of longitude. On the west the unbroken North American coast-line bounds another 90° (approximately) and the remaining 90° of longitude are occupied by the Atlantic-Arctic junction, into which, however, there projects from the north the triangular land-mass of Greenland. Thus the Arctic Ocean is nearly surrounded by continental land and it lies, itself, round the Pole but placed rather more to the east than to the west. As we shall see presently this is almost exactly the opposite kind of distribution of land and sea that we find in the south polar region. There the Pole is surrounded by a great, continental land-mass and round about this, again, is the continuous southern ocean.

North from the Canadian coast and that of Greenland are a number of islands which form the North Canadian Archipelago. It is these that block up the northern opening of Baffin Bay and it was through among them that the north-west passage towards the Pacific Ocean was to be sought.

Hudson Bay, we also see, is a huge inlet into the North American Continent bounded on the west by the Dominion of Canada, and on the east by the peninsula of Labrador. The mouth of the bay is almost filled up by a number of small islands, the biggest of which is Southampton. Then across these again is the large irregular island called Baffin Land, so that between this and Labrador lies the entrance into the bay—Hudson Strait. This strait continues between Baffin Land on the east and the Melville Peninsula of the Canadian mainland as Fox Channel and Basin, which contract to the very narrow channel called Fury and Hecla Strait. In order to make a north-west passage—*on the map*—*viâ* Hudson Bay we have therefore to pass through Hudson Strait, Fox Channel, Fury and Hecla Strait into the Gulf of Boothia. This route has proved, in general, impracticable on account of the ice.

The extreme northern promontory of North America is the peninsula called Boothia. To the north of this again are the islands of the Canadian Archipelago, so that after passing through Fury and Hecla Strait—on the map—and reaching the Gulf of Boothia we have to pass through the strait between Boothia and the island called North Somerset. This channel, called Bellot Strait, leads into the practicable north-west passage. Bellot Strait is just as inconvenient for actual navigation as is Fury and Hecla. Thus the route *viâ* Hudson Strait and Bay is not, in general, a practicable one.

Leaving Hudson's Strait and Bay we may proceed north into Baffin Bay and then we find—again on the map—sea between the land called Ellesmere and the main mass of the Canadian Archipelago. But here we are so far north that ice blocks the way absolutely so that, instead of passing North Devon, we turn to the west into Lancaster Sound. That leads again into Barrow Strait, and then we turn to the south, between Prince of Wales Land and North Somerset into Peel and Franklin Straits. These lead towards the island called King William Land, and we round this to the west and south, thus reaching the North Canadian coast. Along this there is a practicable route towards Behring Strait. We see that the north-west passage from the Atlantic to the Pacific includes these links—Baffin Bay, Lancaster Sound, Barrow Strait, Franklin Strait, and then along the North American coast. The finding of these passages required the exploration of the first half of the nineteenth century. Now we may briefly glance at the principal voyages.

The Finding of the Passage

Parry. Lieutenant (afterwards Sir) Edward Parry made the first of these voyages. He left England in 1819 with the *Hecla* and *Griper* with instructions to find the passage *viâ* Lancaster Sound. Passing through the latter, and then through Barrow Strait, he was stopped by the ice and found his way south, to the east of Boothia. There he noticed, for the first time, the sluggish behaviour of the compass: he was approaching the North Magnetic Pole at which the directive force of the needle becomes zero. He returned to Barrow Strait and continued to press to the west, finally reaching Melville Island, where his ships wintered. From there he explored by sledging parties, discovering the Parry Islands. Then he returned to England, having crossed the 110th meridian and earned the Government reward. In 1824 he went again by the same route, but went down Prince Regent Inlet (between Baffin Land and North Somerset), lost the *Fury*, found Fury and Hecla Strait, and came home in the *Hecla* in 1825.

The Ross Expedition and the Magnetic Pole. There were two Rosses, Captain John Ross and his nephew Captain (and afterwards Sir) James Clark Ross. Both these sailors left England in 1829 in the *Victory*, which was a small vessel having an auxiliary engine and paddle-wheels 8 feet in diameter (the latter could be lifted out of place when among the ice). They went *viâ* Lancaster Sound and

Prince Regent Inlet to Boothia, where they went into winter quarters. Then they worked with sledging parties and they discovered the North Magnetic Pole in lat. 70° 5′ 17″ N. and long. 95° 46′ 45″ W. They spent three winters on Boothia and a fourth one on Fury Beach (on the south side of North Somerset). Having abandoned the ship they were rescued by a whaler.

The Exploration of the North American Coast. Between Behring Strait (found by Vitus Behring in 1728) and the lower end of King William Land there is an uninterrupted coast-line, that of North America : this was in the course of the north-west passage and it had to be investigated. Captain James Cook had passed along part of it from the Pacific end and the American whalers knew the eastern part well. In the years 1821 to 1826 Lieutenant (afterwards Sir) John Franklin, Richardson and Back made notable journeys along this coast and also followed the courses of some of the American Arctic rivers. In 1837 and 1838 Dease and Simpson, of the Hudson Bay Company, explored other sectors of the same coast, notably in the channel between the mainland and Wollaston and Victoria Lands. Thus by the year 1845 most of the North American coastal sea, not only the open sea to the east but also that between the main and the Canadian Archipelago, had been traversed. At the other end the two channels Lancaster Sound and Barrow Strait had been frequently navigated and there only remained the short north-and-south track, along Peel and Franklin Straits, then past King William Land to the Canadian coast, to investigate.

The Franklin Expedition. It was to do this that the expedition commanded by Sir John Franklin sailed from England in 1845. Franklin, while a young naval officer, had done much exploring work in the North, and he had been, in 1843, Governor of Van Diemen's Land, where he had seen the *Erebus* and *Terror*, under Sir James Ross, sail for their famous voyage of Antarctic exploration. After this cruise both ships returned to England and were immediately recommissioned for a voyage in search of the north-west passage. Franklin, then fifty-nine years of age, was given command with instructions to traverse Lancaster Sound and Barrow Strait as far east as Cape Walker. Then they were to go south from that point and find their way along the North American land. They left England on 19th May 1845. On the 14th July they rounded Cape Farewell. On 26th July they were seen by a whaler in Melville Bay (in Baffin Bay), and from that day they disappeared from

sight. What happened is partly recorded in a paper signed by the captain and first officer of the *Erebus*, which was left at Point Victory (in King William Land) and subsequently recovered. Something of their movements is also inferred from the remains found by the relief expeditions.

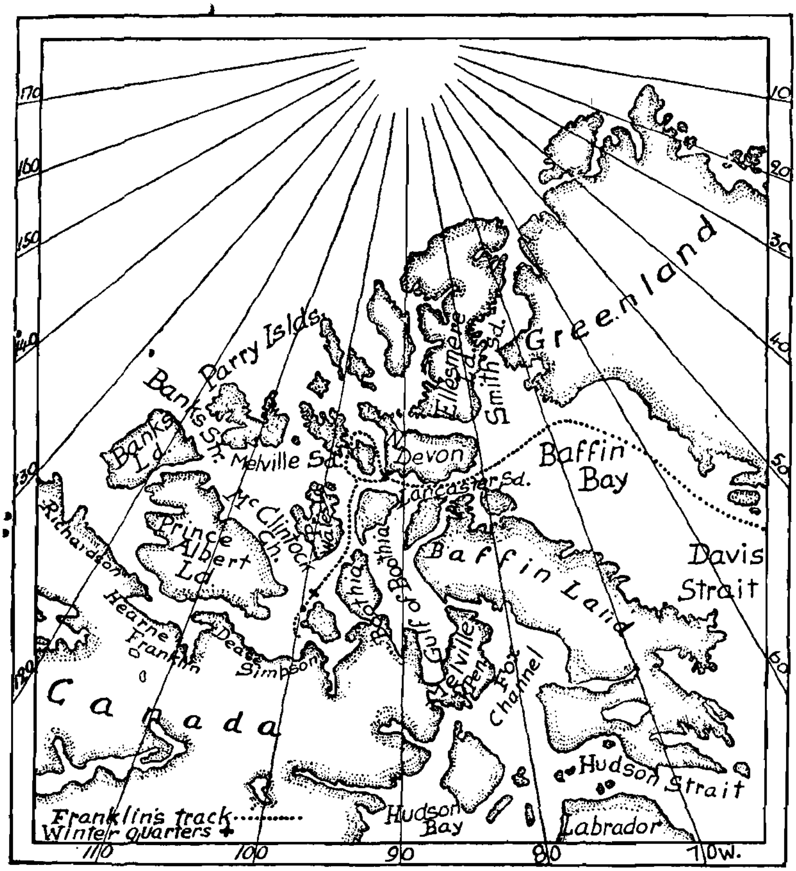


FIG. 20.—Sketch Chart of the Arctic Regions showing Franklin's Route and the North-West Passage.

The probable movements of the *Erebus* and *Terror* are represented on the sketch chart (Fig. 20). They sailed through Lancaster Sound and Barrow Strait till stopped by the ice, and then they went north through Wellington Channel and back south between Bathurst and Cornwallis Islands about 100 miles further to the west in Barrow

Strait. From there they returned on their former course and found winter quarters off Beechey Island (which is at the south-west corner of North Devon). There they remained during the icebound months of 1845–46, and when the conditions became suitable they sailed south—along the connecting path, be it noted—through what are now known as Peel and Franklin Straits, to King William Land. There they wintered, for the second time (1846–47), in lat. 70° 5′ N. and long. 98° 23′ W. Sledging parties explored King William Land. On 11th June 1847 Franklin died. When the summer of 1847 came the ships were still fast in the ice, and so they wintered for a third season in succession (1847–48), but in the spring of 1848 they had to abandon the ships—of which no traces have ever been discovered. The survivors then went south in an unsuccessful attempt to reach the Canadian coasts and find a Hudson Bay post. They followed the coast-line of King William Land and crossed the ice to " Starvation Cove " (on the Adelaide Peninsula of the American mainland), endeavouring apparently to reach, first, the Great Fish River. As they travelled on " they fell down and died." It appears to be probable that they were the victims both of scurvy and starvation, and it is said that some of the food (meat preserved in tins) was probably unsound.

The Franklin Relief Expeditions. When it became certain that the Franklin party had been lost, intense interest, both in the fate of the missing explorers and in their object, was aroused in England and America. The British Government offered liberal rewards to the masters and crews of any whaling vessels that might give information as to the fate of the expedition. In 1859 they offered a reward of £20,000 to the exploring parties that might have rendered efficient assistance to Franklin, his ships or their crews. Lady Franklin also offered rewards. The interest was so great, however, that apart altogether from the inducement of the rewards a number of expeditions from Britain, America and the Hudson's Bay Company searched for traces of the expedition for years. *M'Clure and Collinson*, with the *Investigator* and *Enterprise*, left England in 1850, crossed the Atlantic and Pacific, passed through Behring Straits and entered the Arctic regions from the west. The *Investigator* found the passages called Banks and Prince of Wales Straits, which lead into Melville Sound from the west. The ship was then icebound and abandoned and the crew were taken off by the *Resolute* (a vessel also engaged in Franklin relief work), which then returned

to England *viâ* Lancaster Sound. M'Clure and his party were therefore the first sailors to traverse the whole length of the north-west passage from the Pacific to the Atlantic and they received the official reward of £10,000 for that achievement. *Dr. Rae* was sent, in 1853, by the Hudson Bay Company to search for the missing expedition and succeeded in finding many evidences of their fate. He and his party were paid an Admiralty reward of £10,000 for bringing intelligence as to the actual fate of Franklin and his men. *Dr. Kane* in the *Advance*, an American vessel, searched Smith Sound in 1853–55. Finally Captain (afterwards Sir Leopold) M'Clintock, in the *Fox*, left Aberdeen in 1857 and made an exhaustive search. His party brought back all the news of the missing explorers that it seemed possible to collect. They made important contributions to geographical knowledge of the Arctic regions and they were paid an Admiralty reward of £5,000. During the ten years that followed the loss of Franklin some fifteen vessels had been engaged in the search and the history of the lost expedition was partially reconstructed, while nearly all that was relevant to the existence and practicability of the north-west passage was discovered. From then onwards the quest lost its interest for maritime trade and there remained only a few details for geographical investigation.

The last of the Quest for the Passage—Amundsen. A few crumbs were, however, still to be picked up, and the Norwegian explorer, Roald Amundsen, obtained these. The geography of the region was now known; the ice-conditions could be anticipated and the experience of the older explorers had shown how to avoid the pest of scurvy by carrying suitable food. Above all the internal-combustion engine, using paraffin oil, had been invented so that quite a small vessel could now be used. Accordingly Amundsen, with six companions, left Christiania, in 1903, in the *Gjoa*, a herring-fishing vessel fitted with petroleum tanks and a 13 H.P. "Dan" motor. They followed the Franklin route, through Lancaster Sound, Barrow Strait, Franklin Channel, Simpson Strait and Victoria Strait, emerging finally into the open Arctic Ocean and passing through Behring Strait into the Pacific. They wintered in 1903–4, 1904–5, and 1905–6, and made good observations in the neighbourhood of the North Magnetic Pole. It was a notable, very efficient and admirable voyage, which, however, gave no very new results except that of the actual passage of a ship in one voyage from the Atlantic to the Pacific Oceans *viâ* the Arctic seas.

The North-East Passage

A glance at Fig. 18 will show that there is also a north-east route to India *viâ* the Arctic Ocean. In some ways this must have seemed to be the more practicable one, for the coasts of Russia and Siberia are far more free from the maze of islands and straits than are those of North America. Still the experience of the seventeenth-century English merchant-adventurers disclosed the difficulties that were due to ice, and after setting up a trade with Russian ports in the north the attempt to proceed to the Far East, *viâ* the north coast of Norway and the Kara Sea, was abandoned by the English. Far less attention has therefore been given to the less interesting Siberian seas than to the North Canadian ones. In 1878, however, Baron Nordenskiold made a very notable voyage in the *Vega*, a Swedish vessel. Leaving Gothenburg, in Sweden, on 4th July 1878, the *Vega* sailed along the Siberian margin of the Arctic Ocean and had almost reached Behring Strait when, on 25th November, she became ice-bound. The expedition wintered during 1878–79 and on 18th July of 1879 they were released and sailed through Behring Strait into the Pacific Ocean.

Thus the "all-encompassing ocean" had by 1879 been followed by mariners both to the north and the south of the habitable world, on the east as well as on the west.

The Search for the North Pole

The history of the attempts to reach the North Pole is bound up with that of the discovery of the north-west passage, but the conditions of the two directions of exploration have been rather different. In the case of the search for the north-west passage the ships had to penetrate a maze of islands and straits where the ice-conditions were very variable, but the latter phases of the journeys towards the North Pole meant travelling by sledge, ski or other means, over open ocean covered by more or less persistent ice. Presently we shall examine into the physical conditions of the ocean in the neighbourhood of both Poles and, in the meantime, we can only refer to the more important voyages of exploration that have had the North Pole as their objective.

The Approaches to the Polar Sea. There have always been two routes—to the east and west of Greenland. Going to the east of Greenland the voyagers made the Islands of Spitzbergen (which were discovered by William Barentz, the Dutchman, in 1596 and

which ever after that were the headquarters of the northern whaling industry). Beyond Spitzbergen there is nothing but ice-covered sea into which ships can only penetrate for short distances, so that further advance has had to be made by sledging. On the west of Greenland the explorers have gone through Smith Sound, Kane Basin, Kennedy and Robeson Channels (Fig. 18) into the Arctic Sea and then sledging has had again to be used. The highest latitude to which vessels themselves can reach is not much beyond 82° N.

Principal Expeditions. Henry Hudson, in the "cock-boat" *Hopewell*, with ten men and a boy, set out in 1607 to reach India by sailing over the North Pole. He went to the east of Greenland and then to Spitzbergen, reaching 80° 30′ N. *Phipps*, in the *Racehorse* and *Carcass* (and with Mr. Horatio Nelson as a midshipman and Mr. Israel Lyon an astronomer, sent by the Board of Longitude), set out, in 1773, to find the Pole by proceeding north along the meridian of Greenwich. They made Spitzbergen and then the latitude of 80° 48′ N. *Buchan and Franklin*, in the *Dorothea* and *Trent*, left England with instructions to proceed due north to the Pole, and then to Behring Strait, or alternatively to search for the north-west passage. The officers of this expedition were instructed in making tidal, magnetic and hydrographic observations and pendulum apparatus was also carried in order that experiments designed to discover the precise shape of the earth might be made. They reached N. lat. 80° 37′. *Parry*, in the *Hecla*, and with Lieutenant James Clark Ross, left England in 1827 to find the Pole. They went *viâ* Spitzbergen, carried out sledging expeditions, and attained the latitude of 82° 45′ N. *Dr. Kane*, the American, in the *Advance*, in 1850, in a search after the traces of the Franklin Expedition, went through Smith Sound, found Kane Basin (the enlargement of the strait between Smith Sound and Kennedy Channel) and reached 78° 38′ N. *Hayes*, the American, in the *United States*, in 1860, went north *via* Smith Sound to lat. 77° 18′ in the ship, and to 81° 35′ N. by sledging. *Hall*, the American, went through Smith Sound in the *Polaris* in 1871, and attained the latitude of 82° 16′ N., the highest reached by a ship up to that date. *Captain Weyprecht*, of the Austrian Navy, went in the *Tegetthoff*, in 1872, to find the north-east passage, but, failing in this, he discovered the Franz Josef Islands. *Nares* and *Markham*, with the British ships *Alert* and *Discovery*, sailed in 1875 to find the Pole. The *Alert*, passing through Kennedy Channel, reached the latitude of 82° 24′ N., thus entering

the "Great Frozen Sea." Sledging parties reached 83° 20′ 26″ N. *Greeley*, of the United States Army, left with the *Proteus* in 1881, entered Smith Sound, and explored Grinnell Land.

Nansen and the Fram. We shall see presently that a slow current enters the North Polar Basin *viâ* Behring Strait; also that water drifts across towards Greenland from the Siberian continental shelf. The indications are that this drift traverses the Polar Sea from north-east to south-west, thus probably moving across the Pole. With the moving water flows the icepack. It occurred to Nansen that a ship deliberately frozen into the pack in a suitable place would thus drift, with the ice, across the Pole, and he proceeded in 1893 to put this plan into operation. The vessel used, the *Fram*, was very solidly constructed, so as to be able to resist the very severe pressures she would be sure to encounter when she was frozen into the moving ice: it was expected that when she was nipped between two floes she would lift out from the ice and so evade the worst of the pressure. These anticipations were justified.

The *Fram* was frozen into the ice in about lat. 78° 50′ N. and long. 134° E.: that was on 25th September 1893. The drift as found by regular observations is represented in Fig. 18, and it will be seen that the general body of the polar ice moved obliquely across the North Polar Basin in the direction—New Siberian Islands to Greenland. Thus the *Fram* came to about 6° from the Pole, but when she was in about 84° N. and 100° E. Nansen and Johansen left her and attempted to make the Pole by sledging. They actually attained the latitude of 86° 12′ N., which was, of course, much further north than had yet been reached. Unable to proceed further they then turned and made Franz Josef Land. The *Fram* herself was liberated from the icepack on 9th August 1895, after a two years' drift across the Arctic Ocean.

Clearly the attempt to reach the North Pole by navigating a ship there, either under way or by taking advantage of the ice-drift, was impossible. So also the sledging journeys had proved unsuccessful because, mainly, of the difficulties of resisting scurvy and of taking sufficient quantities of suitable food for men and dogs. Still each attempt to attain high northern latitudes by travelling over the ice was more successful, in general, than the last one because experience of the conditions, difficulties, routes, etc., was accumulating all the time. Such an undertaking, based on other men's experience, then, was sure ultimately to be successful.

The Finding of the Pole. R. E. Peary took the opportunity. After some previous experience in Arctic exploration he made his "dash to the Pole" in 1908. Their vessel took the expedition up Smith Sound, Robeson and Kennedy Channels to Cape Sheridan on the northern side of Grant Land, where they wintered in 1908–9. From Cape Sheridan Peary went to Cape Colombia, on Grant Land, and this was the starting-off point for the sledging journey over the ice. He was accompanied by a negro seaman and some Eskimos, who built snow houses ("igloos") for them, and this very greatly facilitated the journey. They left Cape Colombia on 22nd February 1909, and on 6th April they camped on a spot which Peary estimated as being in lat. 89° 57′ N., thus within 3 miles of the North Pole. After journeying round this final camp, so as to make sure that they had actually been very near to the spot round which the earth turns, they came back to their base. It has been suggested that Peary's observations of latitude were at fault, but there is little reason to doubt that he was as near to the Pole as mattered for any reasonable purpose. The very few details of oceanographical interest that could possibly be observed on a purely "record-breaking" expedition indicate that the party were actually in the neighbourhood of the long-sought spot. The expedition made no appreciable advance in our knowledge of the Arctic Ocean beyond that obtained by Nansen during the drift of the *Fram*, and physical and biological investigations in these very high latitudes still remain to be made.

Finally, in June 1925, *Amundsen* made an attempt to fly by two aeroplanes from Spitzbergen to the Pole and succeeded in reaching N. lat. 87° 44′ and W. long. 10° 20′, where he was forced to descend. The return journey was made by the undamaged plane and the explorers reached Spitzbergen safely.

The Far South

In October 1519 Magellan turned west from his southern course down the South American coast, passed the Cape of the Virgins and entered the Strait that has since borne his name. He sailed through it for thirty-seven days and for over 300 miles until his men became thoroughly alarmed. It was really a considerable voyage, and one can well imagine that Magellan believed that this extensive, mountainous region to the south of his vessels was the Great Southern Continent instead of being a relatively small island part of South

America. On this barren land they could see fires, so that they called it Tierra del Fuego. Long afterwards it was found to be perhaps the most inclement and inhospitable land on the surface of the earth, fit only to be populated by a cannibalistic race who are lower in the scale of civilization than any others that we know.

The Great Southern Continent

Anyhow Magellan, imbued with the ideas that had come down from Ptolemy's map of the world, made over a thousand years before his time, thought that he had sailed through the strait that separated the old, habitable world from the southern frigid world. It is true that Ptolemy's continental land had, by the Middle Ages, been far displaced to the south by the discovery of the two great capes

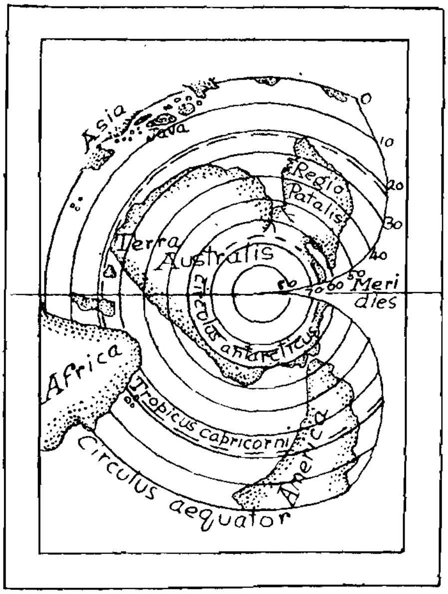


FIG. 21.—The Map of Orontius showing the great Southern Continent. The embellishments of the old engraving are not drawn.

and the open ocean that lay between them both to east and west. Still the idea of the southern land persisted and we see it represented on a map of the period. Orontius' map, which is reproduced in Fig. 21, represents what must have been the geographical notions about the time of Magellan. We see here that men believed in the

existence of a "Terra Australis" surrounding the South Pole and, in one corner, extending as far north almost as the Tropic of Capricorn. The north-west part of this continent was called Brasielle Regio and its north-east part was called Regio Patalis. This part is almost cut off from the rest by two wide and deep inlets and there is a suggestion here that it represents our Australia, which had been seen by some sailor before the time of Magellan. The straits separating the old and new worlds from this southern world are clearly indicated. Magellan's Strait is nearly in the right place and the idea that it separated America from the southern continent is clearly expressed. Between the Terra Australis and Africa the wide strait is also shown with the islands of Zanzibar and Madagascar placed prominently across it.

Thus, with these ideas in their minds, the sailors of the sixteenth century were continually finding land which they supposed to be the southern continent, this identification being quite a reasonable one in those days when the longitudes of the new landfalls were only estimated with considerable trouble and inaccuracy. Let us notice briefly the most important of these discoveries.

Jorge de Meneses, a Portuguese trader, drifted far out of his course in the South Pacific and saw land: this was in 1526.

Ynigo Ortiz de Retes saw the island that we call New Guinea and supposed it to be continuous with Tierra del Fuego: 1546.

Alvaro Mendana, a Spaniard, discovered our Solomon Islands: 1568.

Pedro Fernando de Quiros in 1605 found the New Hebrides.

Thus land was found so often in the south that it was easy to believe—given the preconceived notion—that it all belonged to the southern continent.

The Great Southern Ocean

Towards the seventeenth century, however, the conception of a southern continent rather gave way to that of a southern ocean as the result of further exploration to the south. Thus:

Luis Vaez de Torres in 1606 found that there was sea to the south of New Guinea. He discovered what has since been called Torres Straits, so that he also saw our Australia (though there is evidence that this land had been seen previously).

Abel Janz Tasman, a Dutch sailor, in 1642, found sea to the south

of Australia and discovered land which he called Van Diemen's Land, after the name of his employers: we now call it Tasmania. He also discovered New Zealand, but he thought that this land was continuous with that of Van Diemen and was the southern continent.

Drake and *Dampier* were more sceptical. The former, in 1578, was blown out of his course by bad weather and he went south as far as 57°, so that he must have seen Cape Horn and the sea to south of that. Dampier, in 1688 landed in Australia, but for reasons of his own he was convinced that it was a land in itself and was not joined to any of the other continents.

Captain James Cook finally showed the existence of the great southern ocean which extended all round the world. Cook, who began life as a boy in a collier, rose to a command in the English Royal Navy. In 1768 he was sent out to Otaheite to enable observations of the transit of Venus to be made, and with him went Dr. (afterwards Sir) Joseph Banks and Dr. Solander, as scientific men. The ship was the famous *Endeavour*. On this voyage Cook circumnavigated New Zealand; sailed between New Guinea and Australia; discovered the Society Islands and found a place in Australia so very rich in plant life that he called it Botany Bay. He sailed again, in 1772, with the *Resolution* and *Adventure*, and twice crossed the Antarctic Circle. He circumnavigated the New Hebrides and New Caledonia. He rounded Cape Horn and found the Sandwich Islands and South Georgia. He surveyed New Zealand. He almost circumnavigated the globe in high southern latitudes and he thus left no doubt at all as to the existence of a world-wide ocean to the south of the two great capes.

The Antarctic Continent

Now there was really a southern continent after all—at least that is what we think nowadays—but it was quite clear, after the voyages of Cook, that it was far from being as extensive as the seventeenth-century navigators imagined. Cook had gone as far south as the latitude of South Georgia and he had crossed the Antarctic Circle on two meridians. Practically, then, the southern continent must have been restricted to the circumpolar zone within the Antarctic Circle, and it is within this zone that nineteenth-century exploration has taken place. Now, before taking up the study of the very interesting physical geography of this region we

may summarize briefly the history of the investigations of our period, mentioning the principal expeditions only.

Bellinghausen, the Russian explorer, visited Antarctic waters in 1819. His expedition was a scientific one, for he used apparatus to study the bottom water and its temperature and he made experiments on sea-ice. He filled some gaps in Cook's circumnavigation of the southern ocean. He discovered Peter Ist. Island and Alexander Ist. Land, an island near the Antarctic Continent.

James Weddell—1819–1822—found the great bight between the meridians of 0° and 60° W. which we now call the Weddell Sea. He explored the South Orkneys and South Shetlands.

The Enderbys were a firm of whalers who were much interested in geographical discovery and they gave instructions to the masters of their vessels to make observations. Thus these whaler-explorers discovered the Biscoe Islands, Graham Land (the promontory which points towards Cape Horn) and Enderby Land (which is on the north-east part of the Antarctic Continent). (1830–38.)

Dumont d'Urville with the French vessels *Astrolabe* and *Zélée*. This was a fine voyage of investigation in the course of which Adelie Land was discovered (this is on the south-east of the Antarctic continent). (1830–40.)

Balleny, in 1838–39, found the islands called after his name. At this time interest in Antarctic exploration was very strong and there were three different expeditions in Antarctic seas at the same time—Dumont d'Urville, the American expedition commanded by Lieutenant Wilkes, and the British one under Sir James Ross.

Wilkes (1838–42) found what he thought was a continuous coastline extending over the meridians 90° E. to 160° E. He deduced this from snow-clad elevations, but subsequent exploration has not verified the existence of "Wilkes Land," and some parts of it have proved to be only the edge of the great ice-barrier.

Sir James Ross (1839–43) with the *Erebus* and *Terror*. (These were the ships that were afterwards lost in the search for the north-west passage.) With them went Dr. (afterwards Sir) Joseph Hooker, the botanist. Ross made a series of fine magnetic surveys. He boldly pushed his ships through the icepack into open sea outside the ice-barrier along the face of which he sailed. He went into what is now called the Ross Sea, found Cape Adare and Victoria

Land and, what was very surprising, the active volcano, "Mount Erebus," situated on an island in the Ross Sea.

From the time of the Ross Expedition until the last ten years of the nineteenth century important exploration in Antarctic regions almost ceased, but for the short visit of the *Challenger* in February 1874. Then interest revived and again much work was done by the whalers and from 1892 onwards there were a series of voyages ending with that of Captain Robert Scott, who reached the Pole only to discover that Amundsen had just anticipated him.

These later voyages were:

Dr. W. S. Bruce in the *Balaena*: 1892.

Gerlache and *Dr. Frederick Cook* (who afterwards claimed to have been to the North Pole), in the *Belgica*: 1897–99.

Borchgrevinck with the *Southern Cross*: 1898–1900.

The Valdivia expedition, 1898.

Captain Robert Scott (with Dickson and Shackleton) in the *Discovery*. This expedition reached lat. 82° 17′ S. by sledging over the ice: 1901–04.

The Morning and Terra Nova, which were relief ships to the *Discovery.*

The Gauss under Dr. Drygalski: 1901–03.

The Antarctic under Otto Nordenskiold.

The Scotia under Dr. W. S. Bruce.

The Finding of the Pole

As the result of the work of these and some other less important expeditions the way to the Pole was made possible. The places to surmount the edge of the Barrier had been found. The nature of the ice and the difficulties to be met with in sledging over the Antarctic inland ice were known and it was now fairly certain that success was bound to come—all the pioneer work having been done.

So in June 1910 Roald Amundsen sailed from Christiania in the *Fram*. At the time of sailing the destination of the expedition was not disclosed. They arrived at the "Bay of Whales" on 10th February 1911 and wintered until 8th September 1911, when they started on a sledge journey to the Pole. On 2nd December they reached an elevation of 11,075 feet, in lat. 87° 51′ S., and on 14th December they had reached the Pole. No other results of oceanographical or geographical value resulted from this expedition.

Scott's Last Polar Expedition. In 1911 Captain Robert Scott left England with the *Terra Nova* on a voyage to the Antarctic regions. In December of that year the shore party landed on the inland ice and started on their tragic journey to the South Pole. They reached this point only to find the Norwegian flag and the records left by Amundsen. On their way back they were lost in a blizzard. Nothing that has happened since the loss of the Franklin ships and their crews affected the British people so much as the deaths of Scott, Wilson, Oates, Evans and Bowers.

THE PHYSICAL GEOGRAPHY OF THE CIRCUMPOLAR REGIONS

No other parts of the world have had so much interest for English-speaking people during the last two centuries as the circumpolar regions. This has been due partly to the fact that they were, until our own times, the only parts of the world that were left unexplored. They present few features of geographical interest compared with many other terrestrial areas: everywhere, within hundreds of miles from either Pole, there is nothing but immense expanses of snow and ice, and the only features that break this monotony are those minor irregularities of the ice surfaces that have made travelling over them so incredibly difficult. We search for the fascination that these dismal regions exert on our minds partly in the strangeness of the astronomical conditions that exist and partly in the romance that has always been attached to the history of their discovery.

That there are little regions (not *points*, as we shall see) round which the great body of the planet slowly rotates is a thing that makes powerful appeal to the imagination of the student and traveller—and the appeal is largely an intellectual one, for the mere appearances do not suggest at all the turning round of the earth, but the turning of the heavens. We linger for a moment on these matters.

Astronomical Conditions. Just because the earth is (very approximately) spherical there must be regions of different temperature on its surface. We know that the sun's heat is far more strong about midday, when he is most nearly overhead, than it is in the morning or evening, when his rays fall on the earth in a slanting direction. So, at the region of the tropics, the sun's rays fall nearly perpendicularly to the surface of the ocean or earth and a unit of area, say, 1 square mile, receives so much heat. But near the Poles the solar radiation strikes the earth's surface at a small angle and the same

beam of radiation that is received by a square mile at the tropic is received by very many square miles at the frigid zone. Therefore the temperature of the air, earth or sea is greatest in the torrid zone and least in the frigid zones.

Now if the axis of the earth were perpendicular to the plane of the orbit round the sun the temperature of the surface would vary regularly from the Equator to the Poles just as we have indicated and *there would be no seasons*—only those small, inconstant changes from day to day that are due to "weather." There would be *climes* but no change of winter and summer at the same place. At present the earth is nearest to the sun at one time in the year (the position of perihelion) and furthest six months later (the position of aphelion), and so the quantity of heat received varies *a little* because of this. But the effect is very small.

However the axis of the earth is inclined to the plane of the orbit at a constant angle of 23½° and so we have seasons. Study of the diagram of Fig. 22 will easily show that when it is summer in the Northern Hemisphere the rays of the sun fall more directly on the earth surface because then the earth's axis is inclined *towards* the sun. When it is winter in the north the axis is inclined away from the sun and so less heat is received. Thus we have not only the variation according to latitude, but also a variation according to the season.

Now take the conditions as they are actually to be experienced at the Poles. As we go north, during the northern summer, the day becomes longer and longer until at about the latitude of North Cape the sun only sets for a few minutes at the middle of summer. At the Pole he does not set at all for six months, and then, for other six months, he remains below the horizon. The *appearance* is as if the sun continually revolved in the heavens (with reference to some fixed object at the Pole) during the six summer months.

But at the beginning of these months he would be low down touching the horizon and then, day by day, he would creep up a little higher into the heavens, attain an altitude of 23½° and then, day by day, he would decline lower and lower, until he disappeared below the horizon altogether. His *apparent* path in the heavens would thus be a spiral one.

In a sense, it is always " noon " during the summer *at* the Pole, that is the sun is always south and his altitude in the heavens is sensibly the same at all hours in the day : it varies from day to day

by an exceedingly small amount, just as meridian altitude of the sun varies from day to day in our latitude, being greatest at midsummer and least at midwinter.

Everywhere else will be south when one stands at the North Pole and everywhere else will be north when one stands at the South Pole.

The Arctic or Antarctic " night " of six months and " day " of

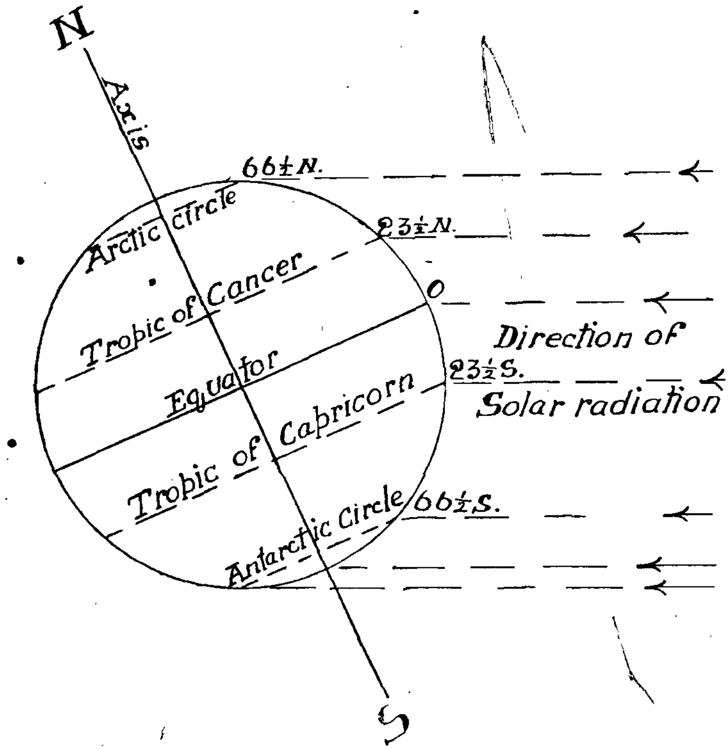


FIG. 22.—The Position of the Earth at the Winter Solstice in the Northern Hemisphere.

six months are not of course " days " and " nights " in our sense. A " day " is really the period of time that elapses between two successive transits of a fixed star across the meridian, and this day is the same at the Poles as anywhere else since it depends on the fact that the earth rotates on its axis with a constant velocity. The polar " six-months day " or " six-months night " means merely the periods when the sun is above or below the horizon.

The " night " is not one of darkness in our sense when we refer to a moonless winter night. The degree of darkness is really far less

FIG. 23.—Sketch Chart of the North Polar Ocean.

Such are the obvious astronomical conditions that explorers experience in the neighbourhood of the Poles.

The Topographical Features. The sketch charts of Figs. 23 and 24 will show clearly the very remarkable differences in the distri-

bution of land and sea in the two circumpolar regions: *one is almost exactly the antipodes of the other.* Thus the Arctic circle bounds

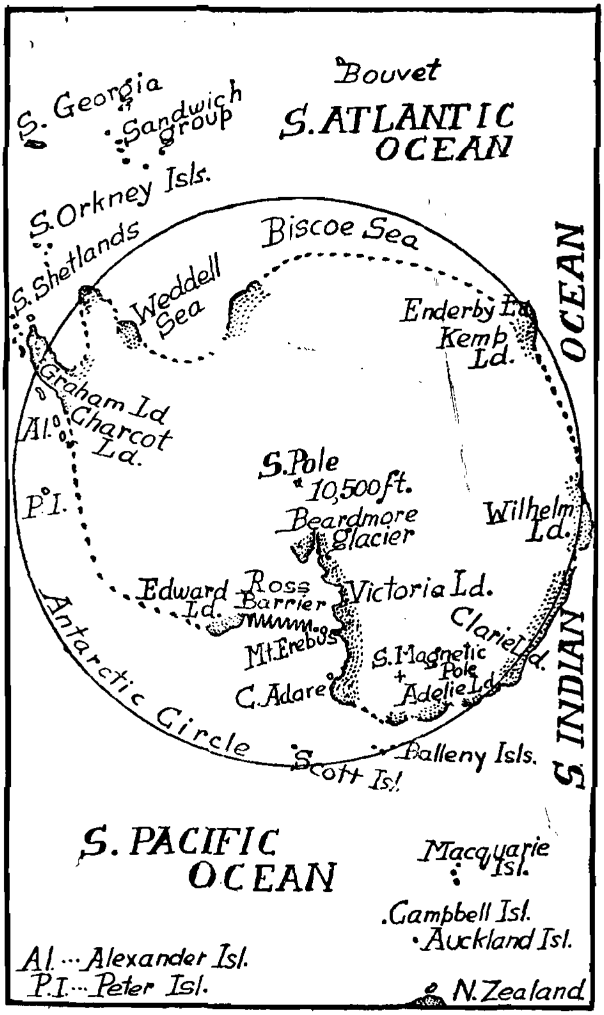


FIG. 24.—Sketch Chart of the South Polar Continent and Ocean.

approximately an area of ocean or archipelagoes, and over a great part of this the depths are of the same order as those that we find in the Atlantic, Pacific, Indian and Mediterranean regions (see later). Round this oceanic area there is an almost continuous zone

of continental land extending through three-fourths of the earth's circumference in the latitude of the Arctic Circle—that is from Norway, through east, north and west to the Boothia Peninsula in Canada, and the only break in this is the very narrow Behring Strait. The remaining quarter of this circle is filled up by Baffin Land and Greenland while the shallow sea across between Greenland, Iceland, the Faeroes and Scotland *divides the Arctic oceanic region from the Atlantic oceanic region.* The north circumpolar region is therefore an oceanic one.

Conversely the Antarctic Circle very nearly bounds a continental region: Graham Land, Enderby Land, Termination Land and Adelie Land all lie on the Antarctic Circle. On the north of the chart and within the Antarctic Circle are the Weddell and the Biscoe Seas, which are mostly on the continental shelf, while to the south-west on the chart and still within the Antarctic Circle is also a shallow sea. Therefore the greater part of the region within the Antarctic Circle is continental land rising to an elevation of over 11,000 feet in the neighbourhood of the Pole. The region within the Circle that is not occupied by continental land is mostly occupied by continental shelf.

Outside the Antarctic Circle and all round the earth in these latitudes is the great southern ocean with depths of 2,000 to 3,000 fathoms. At its least width—between the promontories of Graham Land and Tierra del Fuego—this ocean contracts to about 600 miles, but elsewhere it forms a huge expanse of water, the greatest on the face of the earth. Thus at the South Pole we have continental land surrounded by a continuous zone of ocean—precisely the opposite conditions from those which obtain at the north.

This contrast is really a very remarkable one—so remarkable that it cannot be without significance. We have seen, in Chapter I, that it *has* significance for any theories that we can make with regard to the mode of origin of the oceans and continents.

The Oceanography of the North Polar Basin. The knowledge of the depths of the sea and of the tides and currents that has been obtained mainly during the latter decades of the nineteenth and the first decade of the twentieth century adds immensely to our conception of the North Polar Basin as a truly oceanic one. The sketch chart of Fig. 25 illustrates this conception and summarizes the main results of the scientific voyages of exploration in the northern regions.

Here all the stippled region represents continental shelf; the area shaded by lines represents water which is 1,000 to 2,000 fathoms in depth. We see now that the Arctic ocean basin—that is, the region of oceanic depths, lies round, but mostly to the north and east of the Pole. Then adjacent to the Continental land—that is, Europe, Siberia, America and Greenland—there is a very wide zone of continental shelf. On this shelf are situated the continental islands—those of the North Canadian archipelago, the Spitzbergen, Franz Josef, Nova Zemlya and New Siberian groups. Thus continental land, continental shelf and continental islands surround and isolate the Arctic oceanic basin.

Between Greenland and Norway there is a region of oceanic nature—the Norwegian Sea—which has a depth of from 1,000 to over 2,000 fathoms. This also is isolated to the north and south by shelf. On the south an irregular zone of shelf which has a depth of not much over 300 fathoms extends all the way across from Iceland to Scotland. Now while we may, from the general appearance of the chart, be inclined to regard the Norwegian Sea as merely the most northerly part of the Atlantic Ocean and think about the southerly boundary of the Arctic Ocean as extending across the region from North-east Greenland, through Spitzbergen and Nova Zemlya to the Siberian coast, this region of shoals from Southern Greenland to Scotland leads us to take a rather different view.

The Iceland-Faeroe-Shetland Ridge really bounds the Atlantic Ocean to the North, inasmuch as it prevents all but a superficial drift of water from the Atlantic to the Northern Ocean. The dotted lines on Fig. 25 represent the directions in which water drifts on the surface from Atlantic to Arctic and the broken lines show the cold currents. Thus Atlantic water, which is warmer and salter than that which is normally present in the Arctic region, flows, *on the surface*, up past the west coast of Ireland, then through between the Faeroe Islands and the Shetlands and up along the west coast of Norway. Some warm and salt Atlantic water also flows on the surface and can be recognized to the south of Spitzbergen, while another branch of the "Atlantic stream" flows over towards and round to the north of Iceland. Now when it is near Spitzbergen, and in the Barentz Sea, this Atlantic water cools down to the temperature of that normally present in the Arctic Ocean, but, being salter than the latter water, it thus becomes heavier, sinks to the bottom, and continues to flow on in the same direction.

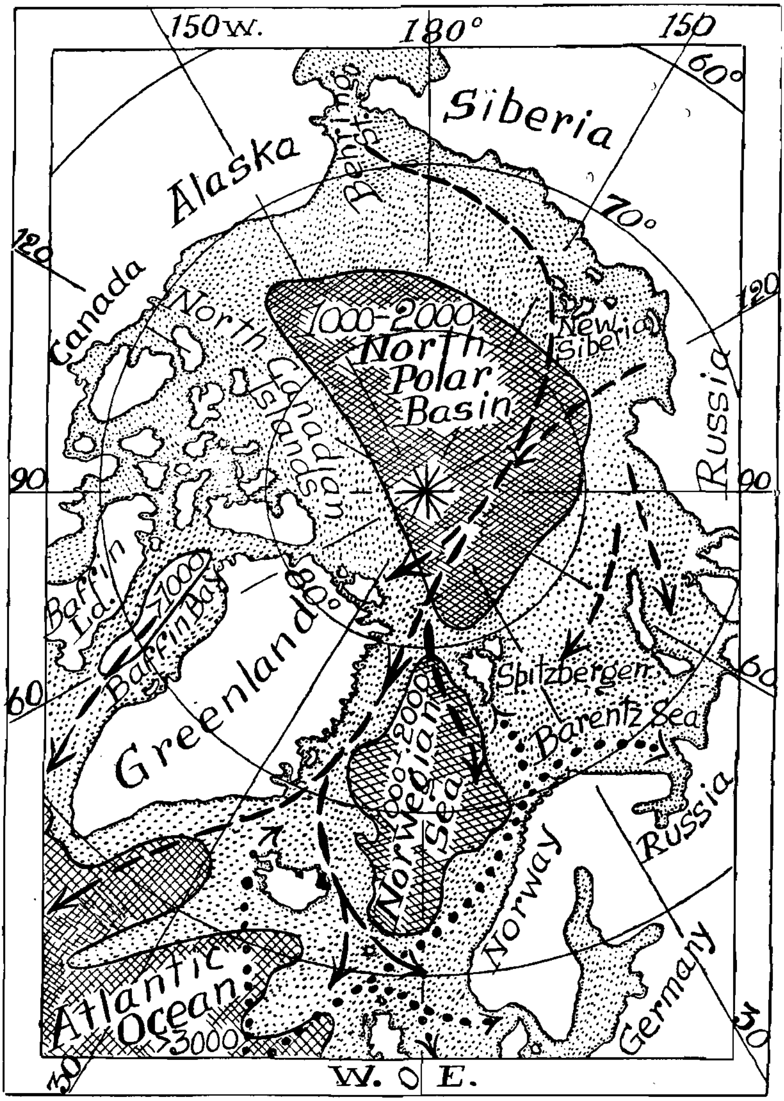


FIG. 25.—Oceanography of the North Polar Seas.

Stippled parts represent water that is less than 1,000 fathoms in depth and parts shaded with lines represent water which is over 1,000 fathoms in depth. The broken lines with arrow-heads show the directions of *cold* currents. Lines of dots with arrow-heads show the directions of *warm* currents.

This, however, is only the superficial Atlantic water. The zone of shoals from Greenland to Scotland prevents the flow of the bottom Atlantic water and so we find that, to the south of about latitude 70° N., this bottom Atlantic water has a temperature of 4° to 7° C. while the bottom Norwegian sea water has a temperature of 0° to 4° C. Thus the Norwegian and Arctic Basins are filled with very cold water while that which lies in the lower strata of the Atlantic is much warmer. Therefore the *physical* Arctic oceanic basin includes that of the Norwegian Sea.

The broken lines with arrow-heads in Fig. 25 represent the directions of flow of water *from* the Arctic Ocean. These directions have been deduced from observations of the drift of wreckage and ice, and also from the observed movements of Nansen's ship, the *Fram*, with other similar drifts. Summarizing them we see that some water enters into the Arctic region through Behring Strait; that water coming from the great rivers that open out on to the Siberian coast flows across the Arctic Ocean from north-east to south-west; that a prominent, cold, southerly-flowing current goes along the east coast of Greenland and even across towards the British Isles. The East Greenlandic current joins with one coming out from Davis Strait and continues to flow to the south as the well-known Labrador Stream.

Oceanography of the Antarctic Region. We know far less about the depths, the currents and the tides of the Antarctic Ocean than we do about the north polar region. Close to the various Antarctic lands—Graham, Prince Regent, Coats, Enderby, Kemp, Adelie, Victoria and King Edward—there is a 1,000-fathom contour which bounds the continental shelf. But, it will be noted, it is only in the neighbourhood of the best-known region—Graham Land and the Weddell Sea—that this contour is really drawn as a continuous line on the charts, and elsewhere its existence is hypothetical. Just outside it is the 2,000-fathom contour, and in many places this also is hypothetical. The fact is that notwithstanding the number of recent expeditions to the Antarctic region there are very few soundings compared with the magnitude of the region.

Now the depths round about Graham Land and Cape Horn are very interesting. The Patagonian shelf, on which the Falkland Islands are situated, extends far out from Cape Horn. Also the continental shelf round Graham Land extends out to the north-east so as to take in the South Orkneys and Shetlands and the Sandwich

group and then appears to curve round towards South Georgia. That means that the continental plateaux of South America and Antarctica are *nearly* joined by shelf and there is all the appearance of an insular arc curving round between Cape Horn and Graham Land. The islands of this arc are the Falklands, South Georgia, the Sandwich, South Shetlands and South Orkneys, and these may be regarded, *in the meantime*, as the most elevated summits of a great curved earth-fold joining the Antarctic and South American mainlands.

The Antarctic Continent. Now the reader will see that there is still the old problem of the " Great Southern Continent," that is, we have yet to dispose, one way or the other, of the old idea that has come down to us from the time of Ptolemy. It is quite possible that the two seas, Ross Sea and Weddell Sea, cut completely through the Antarctic Plateau and that the latter is, not a great, continuous landmass at all, but rather an archipelago. The evidence that we do have points, however, to the continental conception and, in any case, the whole area is one situated on an extensive region of continental shelf even if it does consist of a number of large islands. That is, Antarctica belongs to the category of earth-elevation regions while round it in all directions there is a region of earth-depression filled by the Southern Ocean.

Generally speaking cold and relatively fresh water drifts out from the Antarctic region. If we look at charts showing the prevalent directions of the oceanic currents we see that at the southern ends of the Atlantic, Pacific and Indian Oceans there is a " west wind drift " of surface water. Thus all round the world, in the southern ocean, cold water drifts slowly to the west and north from the Antarctic oceanic region up into the eastern sides of the other oceans.

Polar Ice

Now we have, so far, written about the north and south polar regions just as we have done in respect of the Atlantic, Pacific and Indian Oceans—that is, we have regarded them as *water* regions. And so they are in the chemical sense, but over the greater parts of the Arctic and Antarctic regions the water exists in the forms of snow and ice and it is this condition that gives extraordinary interest to the circumpolar earth-regions.

Formation of Ice. Ice which is found in the sea may originate

either in the sea itself or on the land. First we consider the way in which land ice is formed. There is a continual circulation of the atmosphere. Water is being evaporated from the surface of the ocean in the torrid and temperate zones and the vapour so formed is carried in wind currents to other parts of the earth's surface. A large part of this water vapour is carried to the polar regions, where it becomes frozen and falls to the surface of the earth as snow. Thus liquid water is evaporated from the tropical and temperate ocean, is carried as vapour in the atmosphere, and descends on the polar regions as frozen water.

Now if this snow that descends (or is *precipitated*) on the polar regions were to accumulate *all* the water of the ocean would tend to become deposited round the Poles as "ice-caps." It is quite possible that this has happened in the planet Mars, where the white, polar ice-caps are very conspicuous features (we do not know, however, whether the material of these Martian ice-caps is really water and not solid carbonic acid). Something of the same kind actually happens on the earth—that is, we have a deposit of *water* on the high land of the Antarctic continent, on Greenland and Iceland, where it lies in the form of snow and ice. The snowfall on the immediate circumpolar regions is probably much less. At certain periods in the past there has been a much more extensive deposition of water in these regions—that is, during the "great ice-ages," or epochs of glaciation. At these times the general level of the ocean in the tropical and temperate regions must have been temporarily lowered because of the removal of water by evaporation and the accumulation of this as ice in high latitudes either in the north or south.

Thus snow tends to accumulate on the polar land surfaces. The fall may not be large, yet it is continual, and the snow does not melt (or a very large fraction of it does not melt). It accumulates in the form of *nevé*, that is, as thin strata or layers of compressed snow gradually passing into the form of ice. Everywhere on the land round about the Poles this land ice forms, and it would accumulate there if it did not tend always to creep down into the sea.

Large regions in the North—Greenland, parts of Iceland, Spitzbergen, the North Canadian Islands, etc.—are thus covered by inland ice resulting from the accumulation of compressed snow. All over the Antarctic Continent there is such an ice-cap consisting of ice having a very definite stratification. This is always being added to,

yet the polar ice-caps do not grow in thickness indefinitely and so we conclude that their substance must be removed in some way.

Glaciers. The ice of the land-caps is a brittle solid, yet, in great masses, it is plastic, or viscous, so that it can "flow." It adapts itself to the irregularities of the land surfaces and so fills up valleys. Wherever there are slopes the land ice tends to move downwards, being moved on by the pressure of the new ice that is always forming on the higher levels. Thus all the valleys are filled up by *glaciers*, huge river-like masses of ice that are slowly moving down to the sea by reason of their own gravitation. The glaciers break, adapt themselves to the forms of their beds, unite again and so creep at a slow but measurable rate towards the ocean. The enormous pressure exerted by them, just because of their weight, breaks away rocks, stones, etc., from the beds. These rocks and stones are carried in the bottom layers of the glaciers and so they scratch and erode the beds, gradually excavating these out into deep gorges. Thus the tendency of the formation and motion of inland ice is to wear down the surface of the land.

Glacier Icebergs. The end of the glacier comes to project out from the land into the sea. When it reaches water it floats because ice is lighter than water, even fresh water. Thus the free end of a glacier becomes buoyed up when it is pushed out into the sea and, by and by, this upward pressure breaks off the free end of the glacier. Then, with a tremendous uproar, the latter "calves" and gives rise to an iceberg, which is simply a huge mass of ice broken off from a glacier. The berg tumbles over and over again until it floats in the sea in a position of equilibrium. Then it drifts away in whatever direction there is a current, or perhaps it is merely blown by the wind. On the average it must drift to the south (in the case of Arctic bergs) and as it drifts it enters into water that is always becoming warmer. All the time, then, it is melting and as its lower parts melt it becomes unstable and may turn over.

Icebergs in the north are formed mainly on the edge of Greenland. On both coasts there are great valleys, gorges, or fiords filled with glaciers that are continually calving off bergs. Most of these are shed off into Baffin Bay and Davis Straits and then they drift down in the Labrador stream, on the one hand, or in the East Greenlandic stream over towards the Norwegian Sea. The West Greenlandic bergs may reach the latitudes of Newfoundland before they finally

melt. In the North Atlantic Ocean there is, therefore, a southern limit of floating ice.

The Antarctic Ice-cap and Bergs. The formation of the ice-cap and its bergs takes place on a colossal scale on the Antarctic continent. This is entirely covered with an ice-cap (except here and there where the summits of elevated land break through and can be recognized as lands). The southern mass of inland ice is always being added to and so it creeps down into the southern ocean. The edge of the ice-cap where it projects into the sea is called the "great ice-barrier" and it may be a nearly vertical cliff, sometimes between 200 and 300 feet in height. In relatively shallow water the ice-barrier may rest on the bottom and be pushed out to sea along the latter, but ultimately it will reach sufficiently deep water so that it can float. Then, just like the glaciers, it will become buoyed up and when the buoyancy of the floating part has increased sufficiently enormous masses will break off—that is, the Barrier will "calve."

These Antarctic icebergs are very large. They may be as much as 20 to 30 miles in length and they have a height above water of about 150 feet. Since about seven-eighths of the total height is below water the volume of these antarctic icebergs must be enormous. Characteristically their general shape is tabular: steep sides and flat tops. That is they are fragments of the great stratified sheet of ice that covers the Antarctic land.

Formation of Sea-ice. Fresh water freezes at 0° C. As the water cools down it contracts in volume and this contraction proceeds until the temperature of 4° C. is reached, when the water begins to expand. Still cooling, it expands until the temperature of 0° C. is reached, when the expansion ceases and the solid ice crystals form. If the solid ice is cooled below 0° C. it contracts.

Sea water freezes at a lower temperature than fresh water because of the dissolved salts that it contains. As it freezes the salt crystals tend to separate out so that frozen sea water contains much less salt than does unfrozen sea water. In *old* ice-floes the frozen sea water is practically fresh—that is, it can be melted and used for drinking or cooking. When sea water freezes the unfrozen part becomes salter and this cold, heavy, salt water tends to fall down to the sea bottom.

The Kinds of Sea-ice. When the temperature of the sea falls to about —1·7 C. (29° F.) and when the sea itself is calm, ice-crystals separate out and become visible on the surface. If snow falls at

the same time neither it nor the ice-crystals melt and the surface of the sea becomes covered with a soft "slush." The ice and snow crystals are not attached to each other at the time of their formation and so the surface of the sea is at first pasty, but later on the slush solidifies to a crust covering the unfrozen water and this crust is still plastic. It is called "bay-ice" and it may be as much as 4 inches in thickness. It is black and translucent, or white and opaque in appearance.

When the sea is rough the slush and bay-ice tend to form in separate cakes which are rounded or polygonal in shape and vary in size from a few inches to a few feet. These are called "pancake-ice" and they form a kind of patchwork on the surface of the sea. If the temperature continues low so that ice-formation goes on the pancakes gradually coalesce to form "floes," which are sheets of ice up to about a mile in diameter and about 5 feet in thickness. The floes increase in size mainly by being driven together, or over and under each other, by heavy seas. At first they have a rough and sticky surface and this is salter than the ice in the thickness of the floe. As the floes grow older the quantity of salt on the surface or in the depths of the ice decreases so that in a very old floe which is melting on the surface by solar radiation the little pools of water that are formed are fresh—or, at least, treatment with a solution of nitrate of silver gives only a faint opalescence, such as may sometimes be seen in ordinary water supplies. In all polar expeditions floe ice has been used to supply drinking or cooking water.

If the sea continues to be calm and if the temperature remains low enough floes of indefinite size will form. If this is the case, and the floes are so big that they appear to extend everywhere when seen from the masthead of a ship, we have "field-ice." But usually violent winds and seas break up the floes and the field-ice into a confused mass of large ice-fragments which is called the "pack." All polar exploration involves the navigation of a ship through the pack and through the "lanes" of water that lie between the floes. The ship is insinuated between the floes, or she may actually charge and shatter the latter, forcing a passage through the broken fragments. Whalers and other vessels intended for ice navigation are constructed to resist the pressure of the ice so that they may actually be "nipped" between floes without undergoing damage. "Ice-breakers" are vessels built to force a way through the field-ice or pack: when the ship is made to charge a floe her bows rise up on

the surface of the ice and the weight of the vessel breaks down the latter. All polar navigation and whaling operations proceed in these ways, risks being taken by experienced ice-mariners that are, of course, inevitable ones.

The Paleocrystic Sea. Inside the 80th parallel of latitude in the Arctic region the ice is *old*—centuries old, M'Clure thought. Peary in his journey to the pole from Grant Land tells about first traversing the glacial ice on the shallow water near the land. After passing this "glacial fringe" they came to the "shore-lead," the zone where tidal action shattered the ice, and beyond this was what Markham called the "Paleocrystic Sea"—the sea of ancient, rock-like ice. Here the constant movements of the ocean had piled the floes on each other until the ice was 20 to 100 feet in thickness. But it was not all such ancient ice, for between these old floes there was directly frozen sea water, ice about 8 to 10 feet in thickness, and here and there might be water lanes, or cracks between the floes, which were up to 2 miles in width. On the old ice there were "pressure ridges," rough zones where the up-ending and grinding of the floes and their collisions with each other had piled up the ice to (sometimes) ridges of ¼ mile in width and some 10 to 30 feet in height. Here, and on the inland ice as well, were "hummocks," low irregular hills of ice. On the old inland ice are crevices where the ice sheet had cracked because of its adjustments to changing levels. An appreciation of the enormous difficulties of sledging over the inland or ancient floe ice is easily attained when one reflects on these conditions.

Everywhere, of course, the ice is in motion. On the inland ice-caps (as on Greenland and on Antarctica) the whole mass of ice is sliding down slopes into the valleys or into the sea. The motion is very slow and only appreciable by rather exact measurements, but in its course there are violent adjustments so that great cracks, or crevasses, open and close. In the polar ocean there are small tides and these do not (probably) move the ice to any extent, but there are slow currents (see Fig. 25) and, as a result of these, the whole ice-pack moves slowly. If there are areas of open water then seas are caused by violent winds and so the pack is set in motion. In the seas round the polar ocean proper,—in Baffin Bay, Davis Straits, off the American coasts, in the channels of the Canadian Archipelago, etc., the seas caused by violent winds may induce very large movements of the icepack and these are greatest about the times when the field-ice breaks up at the beginning of the Arctic summer.

Life in the Circumpolar Seas

The Greek geographers, as we have seen, placed the *habitable* world in the north temperate zone. If there was another habitable world this would be situated in the corresponding south temperate zone. They thought that the intertropical or torrid region would be void of human life because of the extreme heat, while the frigid regions would also be uninhabited because of their intolerable cold. Note that they deduced the existence of hot intertropical and cold circumpolar regions, though they had no experience of these parts of the world.

Now the voyagers of the fifteenth and sixteenth centuries found that man existed on the earth wherever they went, on the equatorial regions as well as in Tierra del Fuego. When explorers came to search the Arctic world they found man there also, except in the Paleocrystic Sea (where the Eskimo found hunting difficult or impossible.) Man was not found in the Antarctic continent or its islands, a fact which indicates that this part of the world was isolated from America before the human race had evolved and that until the nineteenth century man had not been able to invent the means of migration across the wild southern ocean.

But few extensive regions have now remained unvisited by explorers (except the tops of the very highest mountains), and although there are no permanent human habitations in some places this indicates only that man has not yet thought it worth while to invent the means of establishing himself there.

Lower Forms of Life in the Frigid Zones. Everywhere upon the earth life exists, even in the hottest deserts as well as in the coldest seas and lands. Particularly we may note that *wherever there is sea there is also abundant life.* Even in the ice and snow there is plant life in the forms of diatoms, which discolour the ice of bergs, and a red alga which discolours snow. The sea everywhere in the Arctic and Antarctic regions is teeming with life—for instance the extraordinary abundance of whales and seals in both Arctic and Antarctic seas before the ruthless slaughter initiated by modern industrialism began. Even now the incredibly great wealth of bird life in the Antarctic, as seen in the penguin rookeries, is an extraordinary thing. In the sea itself animal life of all kinds, both in the surface waters and on the bottom, is more dense in the polar regions than it is in the intertropical ones.

On the circumpolar lands life is less abundant by far than it is on

the temperate or tropical lands—this applies particularly to plant life. Nevertheless there are abundant flowering plants in the Arctic lands, though only two or three species have so far been found in the Antarctic continent. Mosses and lichens are found in both circumpolar lands almost everywhere. Animals are to be found everywhere inside both Arctic and Antarctic Circles, but there is this remarkable difference: many kinds of mammals exist in the Arctic islands and on the frozen seas there, but no land vertebrate animal has been found on the Antarctic continent (the penguins are, of course, marine birds). In general the Antarctic land is far less hospitable than that of the Arctic regions.

The Influence of the Circumpolar Regions on the other Parts of the World

This influence is powerful and direct. The mere fact that in the circumpolar regions we have areas of intense cold means very much. Ice forms and breaks away and drifts north and south into temperate latitudes. Winds of very low temperature blow out from the polar zones. The effects are very important inasmuch as it is fairly certain that the "weather" of the temperate zones is very strongly affected by changes which occur in the frigid zones.

CHAPTER V

THE ATLANTIC OCEAN

By the middle of the nineteenth century the study of the topography of the earth's surface had very nearly been completed: thus over four hundred years had been taken up by this kind of exploration. Let us see what it has involved.

First, the mere means of travelling had to be perfected. The ships of Columbus and Magellan were able to traverse the oceans, but they could not penetrate the ice-covered regions of the frigid zones. Very long voyages, and enforced winter rests in inclement and foodless places, had to be provided against; the means of travel by sledges, ski-ing, etc., over inland, or marine ice, had to be discovered by experience, and disease, like scurvy, had successfully to be resisted. Next, accurate methods of surveying had to be invented and perfected. It was not enough merely to be able to visit *all* places on the surface of the earth, but it was also necessary to represent the positions of these places on charts and maps.

The Dimensions of the Earth. The rough form of the earth—that of a sphere—being known from general observations and reasoning, its exact form and dimensions were established. The essential condition for these results was the measurement of a *base-line.* An extensive, flat surface (such as those on Salisbury Plain, or the sands of Lough Foyle, for instances) being selected, a straight line of a certain length was laid down by placing measuring rods end to end, with fastidious precautions, until the distance between two marks had been found to a very small fraction of an inch. Such base-lines are the foundations of all terrestrial and celestial measurements, and one or more have been laid down in every civilized country. From them the dimensions of the earth have been calculated by the principle indicated in Chapter II and employed by Eratosthenes.

The Frame of Reference. The position of every place visited by the explorers is represented by its latitude and longitude. A mesh-

work of imaginary lines is supposed to exist on the earth's surface, that is, a series of lines of latitude running round the earth parallel to the Equator, and lines of longitude passing through the Poles and cutting the Equator at right angles. These lines are drawn on the charts and when the latitude and longitude of a place are found by the explorer this position (of the intersecting lines) is marked on the chart or map.

Navigational Instruments. In the fifteenth century latitude was found by means of the *astrolabe*, an astronomical instrument adapted for navigation by Martin Behaim, the cosmographer. Then Werner, in 1514, described an instrument called the *cross-staff*, which was a great improvement on the astrolabe, and John Davis introduced the use of a still better device, the *back-staff:* this was about the beginning of the seventeenth century. In 1731 Hadley invented the *quadrant* and Halley and others gradually developed this into the very perfect *sextant* of our own times. All these instruments enabled the navigator to find the angle between the horizon and the sun at noon, or between the horizon and the Pole Star. Thus the latitude of a place was found, using such measurements along with tables of the declination of the sun or fixed stars. Longitude was a terrible problem and for a time the only means of finding it was to measure the angle between the moon and the sun, or certain stars. Then, in 1749, John Harrison invented the modern chronometer (which is simply a small and very accurate clock), and this made it easy to find the longitude. The distances traversed by a ship are found from its speed, and this was first measured by the "log-ship." The modern representative of the "log-ship" is the "patent log," which is a little propeller towed behind the vessel. The revolutions of the propeller are communicated to a counter by the tow-rope which turns as the propeller revolves. The counter gives the number of miles run during any period, at the beginning and end of which the instrument is read. Then *plane charts* were constructed, that is, methods of representing distances and angles on the curved surface of the earth by figures drawn on flat, paper charts. The *compass* was perfected. The magnetic surveys made showed how navigators could allow for variation. In these ways the methods of navigation improved—principally during the eighteenth century.

The distance between any two places which are visible from each other can be found by a trigonometrical survey based upon a measured base-line. Now if the latitudes and longitudes of these

places are known the lengths of a single degree can be given in terms of the unit used in measuring the base-line, say, in miles. The length of a degree of latitude differs in the various zones (because the earth is not truly spherical), being 362,748 feet in the neighbourhood of the Equator, and 364,572 feet half-way between the Equator and the Poles. The length of a minute of longitude in the region of the Equator is 6,087 feet, but it diminishes to zero at the Poles, because there all the meridians converge to a point.

Thus the progress of the art of navigation has enabled explorers to represent accurately on charts the forms and situations of the oceans, continents, seas, islands, straits, gulfs, etc., all the *external* features of the earth. That is what one sees on a modern globe, or map of the world, or part of the world. This topographical knowledge of the larger features of the earth is now fairly complete and geography, in the strict sense, has little more to do than fill in details —apart, of course, from its larger and modern humanistic treatment —that aspect of geography which deals with the earth as the habitation of man and considers in what ways physical earth-features have led to the formation of civilizations, and have been factors in the migrations and cultural stages of peoples. Here we deal with physical rather than humanistic geography.

The Beginnings of Physical Geography. Scientific men and explorers have never been content merely to trace the outlines of continents, oceans, seas and islands. When all this has been done the questions arise : Why are land and sea distributed as they are rather than in some other way ? Why, for instance, is the earth not entirely covered with ocean nearly 2 miles deep instead of having about 71 per cent. of its surface covered with water which is, on the average, about 2½ miles deep and the rest dry land which is, on the average, half a mile high ? What was the distribution of land and water in the past ? What changes are occurring at present ? What are the causes of these changes ? And so on. All the great explorers have been interested in such questions and one finds tentative answers to them even in the literature of classical geography. But it has only been during the nineteenth century that the study of the physical geography of the ocean has been made on a really big scale, and most of our knowledge of this branch of science dates back from the years 1872–74, when the *Challenger* made her famous scientific voyage of circumnavigation. Now having traced, in a very summary manner, the growth of our present knowledge of the topo-

graphy of the oceans and seas, we proceed to deal with their physical characters.

The Depths of the Ocean

A physical map of any part of the world is much more than an outline drawing showing, on a frame of reference, continents, seas, rivers, bays, lakes, straits, etc.; it also shows, in various ways, the height of the land surface above sea-level. Prominent mountain chains and hills are marked out so as to indicate their positions, elevations and directions, while the general elevation of the land, apart from the larger features of mountains and hills, is shown by colouring, or contour lines or shading. On an ordinary map (which has the land as its main feature) the ocean is left a blank surface, but on a chart (which usually represents a water region with its coastal, land margins) there are always representations of the depths of the sea and of the nature of the bottom itself.

In all ages a knowledge of the depth of the sea has had immense practical significance to fishermen and sailors. The fisherman is literally *in touch* with the sea bottom, for it is usually there that his fishing gear is working. He must, of necessity, work in shallow water because only if it is shallow can he use lines, hooks and nets in order to get fish. Also fish are much more abundant in shallow than in deep water. The fisherman is always feeling the depth, and long practical experience enables him to visualize the bottom relief as vividly as if he actually could see it. The sailor is either " in soundings " or " out of soundings." If he is out of soundings, that is, if he is navigating seas which are much over 100 fathoms in depth, he has no interest in the depth of water—there is " no bottom." If he is in proximity to the land, or in the neighbourhood of oceanic islands, his main concern now becomes the sea bottom. Near the land, in straits, in the channels leading to rivers, in the approaches to harbours, or along open coasts, *the* important thing to which he must attend is the depth of water that lies underneath the keel of his ship. Sounding the depths now becomes a routine duty of the men who work the vessel.

In these circumstances sailors and fishermen exaggerate the boldness of the " bottom relief " of the sea. Only a very few feet make an enormous distance, because the fisherman has to work in water which is usually less than about 100 feet in depth while the sailor may have to navigate channels between shoals where the water may

only be from 30 to 60 feet in depth (and a big vessel may have well over 30 feet of water between her keel and her water-line). The tide in many parts of Europe may rise and fall by as much as 30 feet, so the sailor must always know by how much the tide will increase or diminish the depth of water that the chart tells him is there. So the terminology of the sailor and fisherman shows this obsession with the matter of sea depth: they speak about "deeps," "holes," "flats," "ridges," "gutters," "rises," "knolls," "brows," etc., referring to differences in the depths of only a few fathoms. Variations in depth which seem enormous to the fisherman look unimportant when one sees the sea bottom after the tide has ebbed out.

Methods of finding the Depth of the Sea. From the most remote times sailors have sounded the sea with the same kind of apparatus. A well-made rope has a lead weight fastened to one end and this is thrown overboard. The leadsman feels the rope run through his hands and stop when the lead sinker touches the bottom. He takes care that the rope is straight up and down at this moment and then he notes what particular mark is nearest to the surface. The line is marked with bits of leather or bunting (the cloth from which flags are made) at the intervals of 2, 3, 5, 7, 10, 13, 15, 17 and 20 fathoms from the end to which the lead is attached. This is the "hand-line" and there is also a "deep-sea lead" which is 100 (or over) fathoms long. The hand-line is kept in a coil, but the deep-sea line is always wound on a reel. The lead not only *feels* the sea bottom but it also *tastes* it because there is a little cavity on the lower part of the sinker and this is filled up with tallow. When the sinker strikes the bottom the sand, mud, stones, gravel, coral, shells—whatever may be there—adhere to the tallow and so the officer on watch gets an idea of the nature of the sea bottom. Fishermen may even *smell* the deposit which adheres to the "arming" of the lead.

When the sea is deep—that is, say, more than 200 fathoms—the ordinary sounding lines cannot be used. Sailors may speak then of "no bottom" and think no more about the matter as an affair of business (though they are very curious about it as an "extra"). The scientists, as well as the engineers who lay the submarine telegraph cables, must however know how deep the ocean is everywhere, and so machines are used for the deeper soundings. Instead of rope the sounding line now consists of a steel wire—usually that which is used for the strings of pianos. It is coiled tightly on a strong reel, and as it runs out it turns a wheel which has a revolu-

tion-counter geared on it. A dial attached to the counter records the length of wire which runs out over the wheel. In such ways depths of over 5 miles can be sounded.

Charts. The Admiralties of all maritime States now make charts for the use of sailors and fishermen. These charts represent the oceans, seas, straits, bays, etc., on a number of scales. They may deal with a part of the ocean, when no land margin at all is represented, or they may (and usually do) show the sea adjacent to some land margin. They show the depth of water, the nature of the bottom deposits, the tidal streams, the lighthouses, bays, beacons, marks on the shore, etc.—all the information which a sailor needs. The depths of the sea are represented by numbers, showing the fathoms, placed on the spots where soundings have been made. These soundings give the depths at low water of ordinary spring tides, and the mariner adds to them the depth representing the height of the tide at the time. This he can obtain from the tide-tables after a short calculation. Sometimes there are specially low spring tides and then he knows that the depth may be less than the soundings indicated on the chart.

The Tidal Zone. On a map there is generally a sharply drawn line showing the common boundary of land and water, but this is not so on a chart—there is, as a rule, *no* sharply delimited boundary where the land ceases and the sea begins. Usually there are two lines drawn on the chart, one representing high water of ordinary spring tides and another representing low water of ordinary spring tides. But sometimes the tide may rise higher up the beach than the level indicated by the first line, or sink below the level indicated by the second one. Between these tidal lines is the *tidal zone* or *foreshore.*

Contour Lines. If we draw a line through or as near as possible to all the places where the depth of water is the same we get a *contour line.* On a British chart these contours are generally—

One fathom		....
Two	fathoms,	.. ..
etc.		
Five	,,	....
Ten	,,	.——.——.——.
Twenty	,,	..——..——..——..
etc.		
Fifty	,,	.....——.....——.....

and in the deeper regions the contours are usually dotted lines with descriptions placed near to them.

Between, say, the 5- and 10-fathom contours we have a zone where the depth of water is everywhere more than 5 and less than 10 fathoms.

The Shallow-water Zone. Adjacent to most of the coasts of the oceans and seas there is a zone of "shallow water." By this we mean a nearly flat zone where the gradient, or slope of the bottom, does not change perceptibly. We may take this zone to be that where the depth is less than about 100 fathoms, but this is only a convenient, and rather arbitrary figure. The width of the shallow-water zone varies. Thus off the coast of Europe, north from the entrance to the English Channel, it is wide, and on it there are the British Islands. On the shores of the Bay of Biscay it is very narrow and it does not exist off the coasts of continental islands (see p. 160), where the gradient of the bottom is (relatively) great.

Now, after this short introduction we may consider:—

The Depths of the Atlantic Ocean

Fig. 26 is a sketch chart of the Atlantic region showing the principal divisions of depth. Now we notice, first of all, that round the continental coasts there is a narrow zone shaded by fine stippling and bounded by a thin line. Everywhere between this boundary line and the coast the water is less than about 1,000 fathoms (about 1 mile) in depth. This zone is the "continental shelf" and we must consider its significance. Fig. 27 shows, on a much larger scale, a part of the Atlantic Ocean out from the coast of Europe. Contour lines, connecting all the places where the water is about 500 fathoms in depth, have been drawn, and this has also been done with regard to the 1,000, 1,500, 2,000, 2,500 and 3,000 fathom soundings. Thus we have a series of zones and we see at once that the contours are closer together between the depths about 1,000 to 2,000 fathoms than they are with regard to the depths that are shallower and deeper than this range. Evidently the distance apart of the contour lines gives us an idea of the degree of slope downward of the sea bottom.

But the slope can be more easily represented by making an imaginary perpendicular section of the ocean, representing distances out from the land on an horizontal scale and depths on a vertical one. The difficulty is that if we make the horizontal and vertical scales the same the figure showing the section must be very large.

This is because the gradient, or slope downwards of the ocean bed, is really very small. If the ocean could be dried up so that we could walk out along its bed we should not, as a rule, recognize any slope

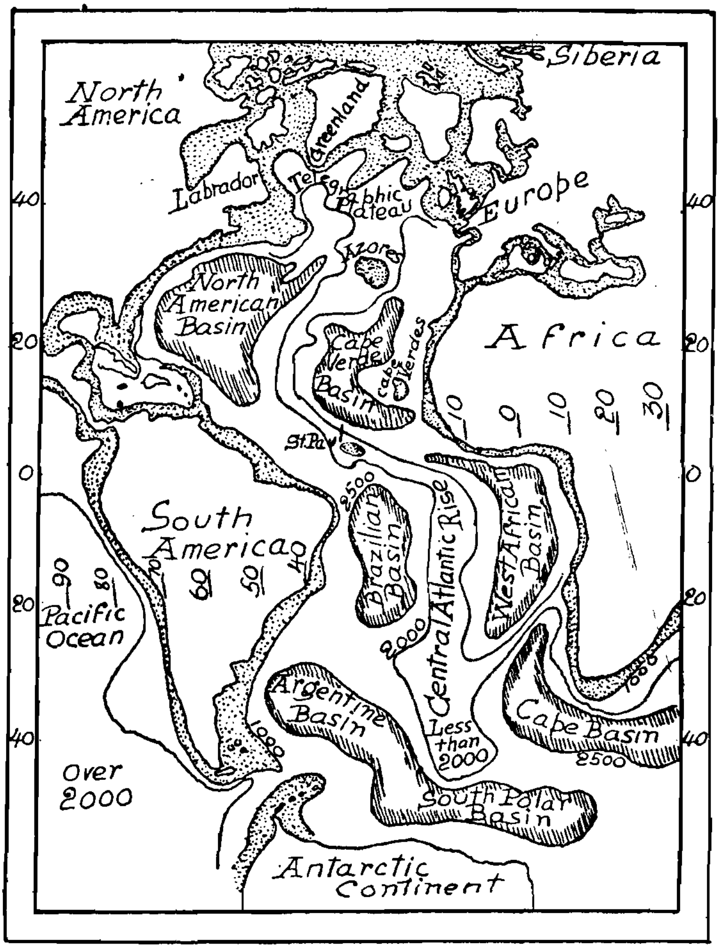


FIG. 26.—General Representation of the Depths of the Atlantic Ocean.
The dotted line round the Continents shows the region of continental shelf and the shaded areas show the basins where the depth varies from 2,000 to 3,000 fathoms.

at all, for this is in most places no greater than the usual railroad gradients—which are really very small ones to our ordinary notions. In some exceptional cases, however, the slopes may be greater. We can get over the difficulty of graphical representation by making the

vertical scale a good deal greater than the horizontal one, and there can be no harm in this procedure so long as the student realizes that *on the world scale the depths of the seas and oceans are exceedingly small ones.* This latter point is very important.

The Continental Shelf and Slope. Fig. 28 represents such an imaginary section made out from the west coast of Ireland along the

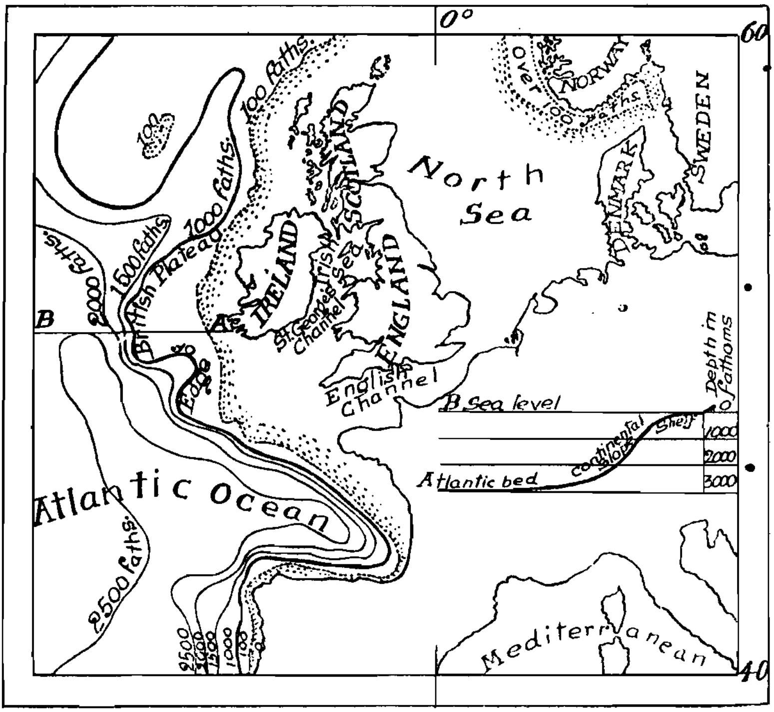


FIG. 27.—Sketch Chart of part of the N.W. Atlantic showing the British Plateau and the Continental Slope.
The inset graph shows a section along the line A–B on the chart.

parallel of latitude 51° N. The depths are shown on a scale of 1 millimetre to 100 fathoms and the distances out from the land are shown on the scale of 1 millimetre to 2 miles. Now we see that there is a flat, shallow terrace round the continental coast, where the depth is everywhere less than 1,000 fathoms. This is the " Continental Shelf."

The Continental Slope. On the " shelf," as we shall call it, the gradient is very small (in this case actually 1 in 250, on the average),

but outward from the 750 contour-line to the 2,500 one the gradient increases (on the average it is really about 1 in 25). This zone of greatest gradient is called the *continental slope.*

The Physical Significance of the Shelf. We must regard the shelf as really part of the continental region. In Chapter I we have considered the great earth features, continental elevations and oceanic depressions. Here we regard the shelf as a transitory zone, very narrow in comparison with the continental and oceanic regions in general, and *inconstant,* in that it has sometimes been dry land and at other times sea bed, while during these changes the oceans and continents have remained constant. The continental shelf is the region in which the sediments of sand and mud carried down into the sea by rivers are deposited. It ought to be (and, in many regions, it actually is) filling up and becoming shallower by reason of the deposition of

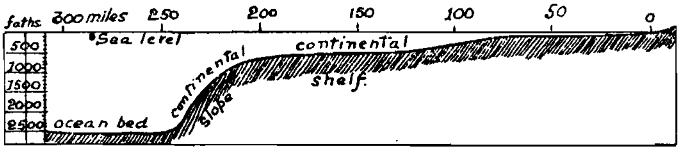


FIG. 28.—Section of the Floor of the Atlantic going W. from Ireland along the parallel of latitude about 51° N.

The horizontal distances are plotted on a scale of ¼ millimetre to the mile and the depths are plotted to a scale of 1 millimetre to 100 fathoms.

these sediments, but there are other reasons accounting for the fact that it may not so fill up. The shelf, then, is a part of the continental rather than of the oceanic regions. The continental slope represents the real boundary between the regions of earth-elevation and earth-depression—it is the narrow zone between continental region and oceanic region.

The Ocean Bed

The ocean bed is the great, flat region beyond the continental slope where the depths are everywhere greater than about 2 miles. In Fig. 26 the Atlantic Ocean bed may be regarded as the whole region outside the stippled zone, which is that of the shelf. This does not mean that the Atlantic has a uniform depth of 2 miles, because there are regions on the chart (indicated by the contour lines) where the depths are less than 2 miles, while there are also larger regions where the depth is nearly 3 miles. But the whole Atlantic region outside the shelf zone is very large, the gradients

everywhere are small ones, and so the general character of the ocean bed is that of an immense, very level plain sunk to an average depth of about 3 miles below the average level of the European, African and American continents. On the latter there is considerable variety of feature: mountain ranges, hills, river valleys with deep gorges and precipices, smaller, but still very varied surface relief—all that one is accustomed to see in ordinary country excepting the great prairie-lands. But on the ocean bed there is, so far as we know from soundings, no such relief. The prevalent feature is that of dead monotony, for we could hardly recognize the gradients that do exist and which our charts and contour-lines and sections must necessarily exaggerate.

Further the materials of the continental land surface are very varied: sandstones, shales, limestones, beds of boulder-clay with stones, igneous rocks, etc. So also the bottom deposits on the shelf present some variety, though the most frequently occurring material there is sand and mud. But out beyond the 1,000-fathom line the bottom materials take on an entirely different character, for everywhere they consist of very fine ooze. At even a few miles distance from the land on most coasts the materials that are brought down to the sea by river water settle down to the bottom, and it is only in the neighbourhood of the openings of very great rivers, such as the Congo, that the sediments are carried far out to sea. Along the shallow-water zone the tidal streams, and the wave motion set up in the water by violent gales, disturb the sands and muds lying on the bottom and spread them out in one direction or the other. But outside the depth of about 100 fathoms the disturbance of the water at the bottom by waves set up on the surface becomes very small, and we may say that outside the 1,000-fathom line the influence of the land on the nature of the materials that lie on the ocean bed becomes very small indeed. We have here another distinction between the shelf zone and the ocean bed: on the former lie materials that come from the wastage of the land and which are accumulating to form sedimentary rocks, while on the ocean bed the materials *come from the water itself.*

Materials of the Ocean Floor. Everywhere outside the 1,000-fathom line the sea-bottom deposit consists of a fine mud, or "ooze," which is soft and rather sticky when wet but which dries to a firm mass. Deep-sea ooze is white, grey, brown, red or blue-black in colour according to its nature. Chemically it consists mainly of

lime, or silica, or clay. Organically it consists of the hard parts of the bodies of microscopic animals and plants that live in the upper levels of the sea, or of volcanic debris. When these organisms die their bodies slowly sink down to the bottom; the fleshy parts decompose and the hard limy or siliceous parts form the deep-sea oozes. The kinds of ooze lying on the ocean bed depend mainly upon the depth of water: thus in moderate depths (say, 1,000 to 2,000 fathoms) there are minute calcareous shells; in greater depths (say, 2,000 to 3,000 fathoms) the limy shells tend to be dissolved by the water and the siliceous shells become relatively abundant; at the greatest depths of all even the siliceous shells dissolve and nothing is left but a very fine reddish clay which consists of the very resistant (or insoluble) residues of the organic skeletons. But there are exceptions to all these general statements and the precise nature of the deep-sea oozes is dependent on more than the depth of the ocean bed.

There are other very interesting things there, such as the teeth of sharks and the earbones of whales. The enamel cones which form the shark's teeth are very resistant and so are the little hard bones that surround the cavities of the internal ears of the whales. So when these big animals die their bodies fall down to the sea bottoms, where the flesh either putrefies or (more frequently) is eaten by the smaller deep-sea crustaceans, etc. Then the sea water dissolves the skeletons and nothing is left but the highly resistant enamel of the teeth, or the equally hard bony material that forms the tympanic bones of the heads of whales.

Minute spheres of iron, or some oxide of iron, with manganese and other substances are also found among the oozes. These are "cosmic spherules" and they are dust that has resulted from the burning of the meteorites that enter the earth's atmosphere from cosmic space. The friction of the air against the meteorite (which is moving at a very great velocity) melts the latter and the oxygen of the air then burns the materials. The latter are mainly iron and manganese. The little droplets of melted oxide of iron fall to the surface of the earth. They must be present everywhere, but there is usually so much other material that it is difficult to find them. On the sea bottom, however, the deep-sea ooze accumulates so very slowly that in it the microscopic cosmic spherules are *relatively* numerous.

We do not know, in the least, how deep a layer is formed on the

ocean bed by the deep-sea oozes, because the only samples we can get are obtained by steel tubes attached to the sounding leads used to obtain the depth of the water. These tubes sink down into the ooze and fill themselves up, but they can only sink down a very few inches. How deep the layer of ooze is, and what kind of rock lies underneath it, we do not know. We can only make reasonable conjectures, and it is very probable that at the bottom of the deep oceans there is volcanic rock. But this notion presents many difficulties and we shall consider the whole matter in more detail later on.

The Physical Conditions at the Ocean Bed. It is possible to find the temperature of the water there, and this is generally only one or two degrees above the temperature of fresh water that is freezing, that is, say, 1° to 3° C. In some parts of the ocean bed (the Norwegian Sea and the Antarctic Ocean) the temperature is actually lower, below the freezing-point of fresh water. This can be the case, for sea water freezes at a lower temperature than fresh water. The low temperature of the water on the ocean bottom is due to the fact that there is a very slow drift, along the bottom, from the polar seas to the temperate ones. Water at the surface in the circumpolar seas becomes cooled and more dense, and so it sinks down to the bottom. Water at the surface in the intertropical zone becomes heated and less dense, and so it flows away on the surface towards the temperate regions. To replace it water rises up from the deeper layers and therefore cold water is drawn along the ocean bed from the polar to the temperate zones.

Lastly a very striking thing about the bottom water of the ocean bed is its extraordinarily great pressure, which is due, of course, to its own weight. A rough estimate of this pressure, and one which is easily remembered, is this: it is about one ton to the square inch for every thousand fathoms (say every mile) of depth. At the bottom of the Atlantic the pressure is, therefore, from two to three tons per square inch of sea bottom. Animals living at these great depths are, of course, exposed to these enormous pressures, but they can withstand them because their bodies are fragile and the water penetrates every part of their tissues so that the pressure is the same outside as inside. Only when they are brought up to the surface do they suffer, for then the pressure to which they are accustomed is diminished so much that the gases that are contained in the blood and other fluids of the body expand and rupture the tissues.

The Form of the Atlantic Ocean

Going back to Fig. 26 we notice, first of all, that the form of the Atlantic is curious and (perhaps) not without significance. The rough outlines of the two opposing coasts, Eur-Africa on the east and the Americas on the west, are similar. If we imagine that these two continents were *movable* on the ocean bed we can also imagine that they might be roughly fitted into each other: the western nose of Africa fitting into the Central American Bight and the eastern nose of South America fitting into the Gulf of Guinea. We have seen that such an hypothesis has actually been made.

The Form of the Ocean Bed. Now we regard the outer margin of the continental shelf as the true boundary of continental and oceanic regions. Looking at Fig. 26, we see that although this margin runs roughly parallel to the coast-lines yet there are some remarkable deviations. Thus the shelf runs from the northern part of the Bay of Biscay, outside the British Islands, south from Iceland and Greenland, towards Labrador. Thus the northern boundary of the Atlantic Ocean bed runs roughly east and west between the parallels of 50° and 60° N., and so the Norwegian Sea bed and the Arctic Ocean bed are shut off from the Atlantic deep water. That means that the sea between Great Britain, Iceland and Greenland, on the east, and between Greenland and Labrador, on the west, are not really parts of the Atlantic Ocean basin.

Then we see that the shelf juts out into the region of the ocean bed in various places: out from Newfoundland and Nova Scotia, in the neighbourhood of the Great Banks; across between Florida and the north-east coast of South America and out to the east from Patagonia. Also we note that the shelf that surrounds Graham Land in the Antarctic projects out in a remarkable way towards the Patagonian shelf. The significance of these extensions of the shelf is this: the shelf is a region where geological changes are much more rapid than on the ocean beds, so that, in comparatively recent geological times, the shelf may have been dry land. Therefore there is not much difficulty in assuming that Northern Europe and Labrador may have been connected together by dry land across the region now occupied by Greenland, Iceland, the Faeroes, the British Islands and the shallow seas between those lands. Also South America may have been joined to Antarctica by an elevation of the sea bottom between the Patagonian and the Antarctic shelves. Elsewhere the opposite shores of the Atlantic are separated by the deep ocean bed.

The Central Atlantic Rise. We see in Fig. 26 another very curious feature. In order not to make the sketch chart too complicated, the unshaded area covers all the region where the water is over 1,000, and less than 2,000, fathoms in depth, while the shaded areas represent depths of over about 2,500 fathoms. These depths, 1,000 to about 2,500 fathoms, are the "ocean bed." In large areas, however, the depth goes down to 2,000 and 3,000 fathoms and contour lines are drawn on the chart so as to enclose these regions of greater depth. Now it will be seen that there is a low submarine elevation extending all the way down the middle of the Atlantic, from Greenland to the latitude of Cape Horn. On this Central Atlantic Rise the depth of water is about 2,000 fathoms, or less, and on either side of it the bottom goes down to 2,000 to 3,000 fathoms. In section, and with an exaggerated vertical scale the central rise is represented in Fig. 29. The rise is a low, wide ridge which runs roughly parallel to the

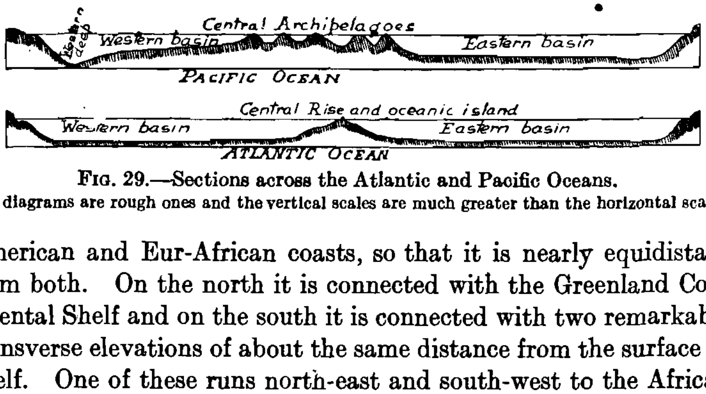


FIG. 29.—Sections across the Atlantic and Pacific Oceans.
The diagrams are rough ones and the vertical scales are much greater than the horizontal scales

American and Eur-African coasts, so that it is nearly equidistant from both. On the north it is connected with the Greenland Continental Shelf and on the south it is connected with two remarkable transverse elevations of about the same distance from the surface as itself. One of these runs north-east and south-west to the African coast and the other runs nearly east and west to the South American coast, in the neighbourhood of the Rio Grande.

Thus there are four "basins" in the whole Atlantic Region: (1 and 2) on the north there are the North American and Cape Verde basins and (3 and 4) on the south there are the Brazilian and West African basins.

The Tributary Seas

What are we to understand by the familiar term "Sea"? To the Greeks of the Homeric period there were only *the* Sea (Thalassa) and the Ocean (Okeanos). *The Sea* was the Mediterranean with which they were familiar and the Ocean was the unfamiliar,

legendary, all-encompassing stream that flowed round about the habitable world. Then, in the time of Herodotus, for instance, other water regions received names: the Erythraean Sea (Indian Ocean), the Sinus Arabicus (Red Sea), the Persian Sinus, the Pontus Euxinus (Black Sea), the Palus Maeotis (Sea of Azov), the Adriatic Sea and the Caspian Sea. Now, in the physical sense, these were rather different water areas, but we see the general notion that was attached to the words which we translate by our term "sea." The latter was a navigable water body having more or less definite boundaries so that it was fairly well known. Thus we read about the Periplus of the Mediterranean or the Erythraean Seas, showing that the coasts of these regions had been traversed and described. Also the seas had individualities because of their human associations, and this kind of interest was something apart from their forms or sizes. The Sea of Galilee and the Dead Sea were small in size, in comparison with the Erythraean Sea, but great in their human interest. So when, at last, the Atlantic became known and had been crossed successfully, Columbus was called the "Admiral of the ocean sea."

Nowadays we use the terms Sea, Bay, Gulf, Strait, Channel, Bight, etc., in this rather loose and familiar way: thus the North Sea, the Baltic Sea, the Irish Sea, Hudson's Bay, the Bay of Biscay, Baffin Bay, the Gulf of Guinea, the Persian Gulf, Davis Strait, the English Channel, etc. The terms suggest the forms of these familiar, bounded, navigable water areas and they have historical associations. But just now we wish rather to fix some precise meaning to the term "Sea" so that it may be useful in enabling the student to visualize natural earth-features that might otherwise be rather arbitrary and difficult to keep in mind.

Water Regions in General. Now we are inclined to divide up the *big* water areas of the world (apart from the ocean) into "lakes" and "seas," the former being completely land-enclosed regions and the latter having communication with the ocean. But first we fix a meaning to our modern term ocean: this is simply the general region of earth-depression—that part of the earth's surface which is, on the average, about two miles below the mean level. The term continental plateau means simply the general region of earth-elevation—that part of the earth's surface which is, on the average, about one-third of a mile above the mean level. Because the earth has water on it this lies in the region of depression, forming the ocean. Some indentations of the boundary between oceanic depres-

sions and continental elevations are filled with water and form lakes. The distinction between landlocked seas, or lakes, and seas that communicate with the ocean is not a very good one because the Mediterranean, the Baltic, the Sea of Azov, etc., are very nearly landlocked and really have been so enclosed in the past. Again the presence or absence of salt in the water is not a very good distinction because, though most landlocked water regions are fresh, others are salt—such as the Dead Sea, or the Bitter Lakes on the Suez Canal. Again the almost landlocked Mediterranean is salter than the Atlantic, while the almost landlocked Baltic is very fresh, or, at the most, brackish.

It is here that the conception of the continental shelf helps us greatly.

Oceans are regions of enduring earth-depression.

Continents are regions of enduring earth-elevation.

The Shelf is the transitory, inconstant region sometimes covered by water and sometimes dry land.

Seas are localized parts of the shelf region during the phases when the latter is below sea-level; or they are shallow, localized depressions of the plateaux. They are inconstant compared with the ocean.

Now see how all this works out. We divide the seas into the two categories, " Epeiric Seas " and " Epicontinental Seas." The terms are not very exclusive in their meanings, but they are now well-known ones and may be adopted with advantage.

Epeiric Seas. Examples of these, in the Atlantic area, are :

Hudson's Bay ;	The Baltic Sea ;
The North Sea ;	The Irish Sea ;
The English Channel ;	The Gulf of St. Lawrence ;

The great American lakes.

Of these Hudson's Bay is an indentation in the oceanic-continental margin and so are the Baltic and the Gulf of St. Lawrence. The North Sea, the Irish Sea and the English Channel are parts of the water-covered shelf region that are partially cut off from the ocean by islands, the North Sea being bounded by the continental land on the east and by Great Britain on the west. The Irish Sea is partially enclosed by two islands, Great Britain and Ireland. The Channel is partially enclosed by the continental mainland and England.

Thus epeiric seas are merely regions of water-covered shelf that are partially enclosed between projections, arms, promontories, etc., of the land, or are bounded by islands. Great lakes like Ontario or the Caspian are epeirics that have lost their connection with the ocean by some movements of elevation of the earth's crust. As a rule epeirics are bounded by low continental land, or islands *which are not volcanic*. They are inconstant when compared with the ocean, thus the North and Irish Seas have been dry land in post-Tertiary times while the North Atlantic Ocean basin has endured since, at least, the end of the Mesozoic period.

Epicontinental Seas. There are seas of quite another kind in the West Indian Island region. If we look at a chart of this part of the world (Fig. 30) we see three *basins*: (1) the Gulf of Mexico, (2) the Caribbean Sea, and (3) a basin lying between Cuba and the Gulf of Honduras—this we may call the Cuban Sea. The most typical of these seas is the Caribbean: this is bounded, on the south, by Panama and the coast of South America; on the west, by Nicaragua and Costa Rica; and on the east by Haiti and the chain of the Lesser Antilles. Now it is the latter boundary that gives this sea its special character.

All three of the basins mentioned have one such boundary made up by a chain of islands strung out in a curve, or *arc*. The Gulf of Mexico is bounded to the south-east by the peninsula of Florida, the western extremity of Cuba and the north-east peninsula of Mexico. The Cuban Sea is bounded to the south by the south-eastern peninsula of Haiti and the island of Jamaica. From Jamaica to Honduras the boundary of the *basin* is formed by a line of shoals—Pedro Bank, Rosalind Bank and the Mosquito Bank (which lies off Nicaragua and Honduras). The Caribbean Sea is, very typically, bounded to the east by the chain composed of Haiti, Porto Rico, the Virgin Islands, the Leeward and Windward Islands and Trinidad; the chain terminating in Venezuela. The general directions of these island arcs are represented in Fig. 30 by the curved lines.

Earth-folds. We shall study other examples of such insular arcs when we deal with the Pacific Ocean, but their general characters can be described here. *Each such arc represents an earth-fold.* A very large part of the crust of the earth is composed of sedimentary rocks—that is, such as have been formed from sediments laid down in shallow seas on the continental shelf. As these sediments accumu-

late they become compressed and hardened into rock by their own weight. They are laid down as *strata* which are usually very distinct. They are laid down very nearly horizontally. As every one knows, these strata must originally have been beneath the sea-level, yet we find that they are seldom horizontally placed, when we can examine them in sections (as on the face of a cliff, or in a railway cutting). Therefore there must have been great pressures at work

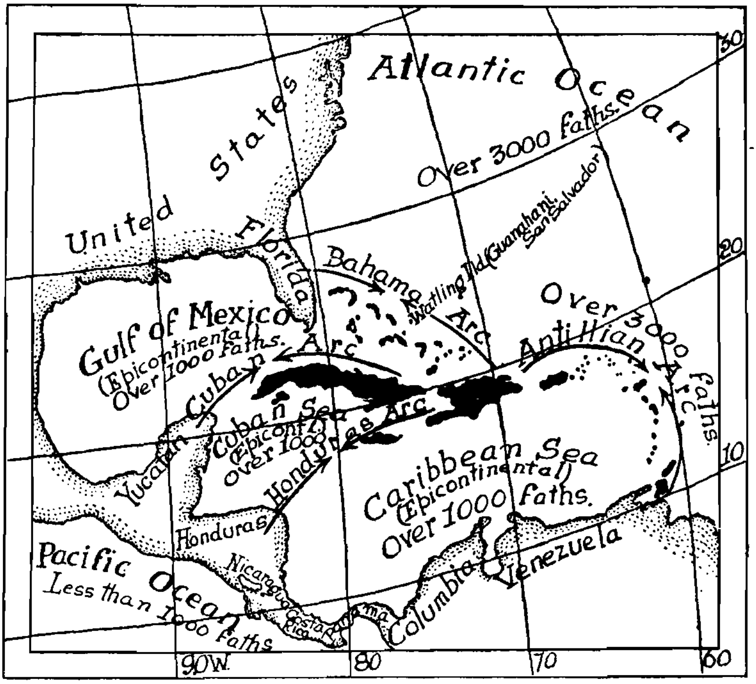


Fig. 30.—Sketch Chart of the Islands of the West Indies.
Islands of the insular arcs are represented in black. Directions of the arcs are shown by the curved lines with arrow-heads.

which have displaced the strata, raising them bodily up, tilting them at all angles to the horizontal and even crumpling, or folding, or contorting them. Now the pressures, or *thrusts*, that have elevated the strata bodily must have been vertical and from beneath; the thrusts that tilt the strata must have had horizontal components; while the thrusting pressures that fold and contort the strata must have been exerted sideways, or horizontally, or mainly so.

Such thrusting pressures are exerted on the great scale and they

have thrown great sheets of sedimentary rocks into complicated folds. It is easy to imitate them on the minute scale—for instance by putting the fingers on the margin of a page of this book and pushing sideways, when the paper will rise up as a low fold. Such foldings have occurred in nature on a gigantic scale and their results form the great mountain chains that we know. The general masses of such mountain chains are made up of folded strata, and the thrusting pressures have been exerted at right angles to the directions of the chains. The folding, by the way, is, in itself, incompetent to form the mountain chain and we generally find, in the core of the latter, igneous rock which has been injected from beneath [1] into the strata. Also there has generally been a movement upwards, from beneath, initiated otherwise than by the horizontal thrusting pressure. Generally all such earth-folds are not straight ones but are curves, because at various parts of the region the thrust is resisted.

Now it is pretty certain that these folds can be set up in the sedimentary rocks lying at the bottoms of shallow seas, just as on dry land. When they occur we have, in theory, an elevation above sea-level but, in general, this theoretically continuous elevation would be eroded away by wave action at those places where the rocks were softest, or were fractured. Or the process of folding may be irregular so that all parts of the elevated region are not at the same level. Therefore we have, in the case of a submarine earth-fold, not a continuous curved ridge but rather a curved row of islands, the latter being the most elevated parts of the fold.

Such series of islands we call "insular arcs" and they form the oceanic boundaries of epicontinental seas. The arcs are always placed so that their convex margins are towards the ocean and their concave ones form the borders of the enclosed sea. Thus the insular arc-folding whose visible parts are the islands of the Lesser Antilles has its convexity facing the Atlantic Ocean. Inside the arc is the basin of the Caribbean Sea. On either side (the convex and concave ones) of the arc of islands is a zone of continental shelf and this usually connects the separate islands. At the extremities the zone of shelf is continuous with the shelf that fringes the mainland. But—a very important feature—the sea basin is not *on* the shelf because it is usually much deeper : thus the Carib-

[1] *Or else the strata themselves may have been melted by the heat developed* by the enormous thrusting pressures.

bean Sea has a depth of about 2,000 fathoms. A typical epicontinental sea basin is therefore to be regarded as a part of the ocean partially separated off by the formation of an earth-fold, the most elevated parts of which rise above sea-level as visible islands. And —again a very important feature—*the insular arc usually carries active volcanoes.* Thus the arc of the Lesser Antilles is notorious in this respect. The presence of the active volcanoes shows that the arcuate insular region *is one of earth-disturbance.*

The Islands of the Atlantic Region

Mainly for the sake of convenience we include here the islands of the Atlantic-Arctic zone as well. We can easily distinguish four categories:

(1) Continental islands;
(2) The islands of the continental shelf;
(3) The islands of the epicontinental arcs;
(4) Oceanic islands.

And this natural classification enables us to take a comprehensive view of the whole Atlantic assemblage.

Now we premise that the whole North Atlantic oceanic region is one of subsidence; that in Mesozoic times there was a great continental plateau where we now have the ocean and that relics of this great geological change are to be looked for in the features of this region. If, then, a great part of the earth's crust in the region between Europe and North America has subsided beneath the waves, we may look for isolated parts of this ancient land. Such isolated parts are:

The Continental Islands. These continental remnants are the North Canadian Islands—the Arctic Archipelago (consisting of Baffin Land, Grinnell Land, Ellesmere Land, etc.), Greenland, Iceland and the Faeroe Isles. The Scottish Highlands are also part of the ancient North Atlantic continent and so are Newfoundland and Cape Breton Island, while Nova Scotia is all but such another outlier of the ancient land—it is still connected with the American mainland. The evidence that these islands are the remains of a nearly submerged "North Atlantis" we consider presently.

The Islands of the Shelf. Most of the British Islands group (see Fig. 27), the Canaries, the Falklands, and a multitude of other small islands on the European, African and American coasts, merely sit on the shelf. Round them is shallow water and they are only the most

elevated parts of the shelf zone So hosts of them are only temporary structures, being of such slight elevation that they are islands only at high-tide level, at other times being connected with the nearest land, either mainland or some other island. They are inconstant in geological time, having occasionally been mainland and occasionally water-covered shelf. Their history has local and antiquarian interest rather than deep geological significance. They illustrate what we have insisted on—the transitory nature of the features of the continental-oceanic margin, or shelf-zone.

The Epicontinental Islands. These (in the West Indian region) we have already dealt with. The epicontinental islands are the results of great earth-movements affecting a large part of the earth's crust, causing an ocean to appear where formerly there was deep sea. The islands of the shelf are the results of local, rather indefinite and slight movements of subsidence or upheaval, but the epicontinental islands result from large specialized movements due to crumpling or folding of the earth's crust along definite lines of weakness.

The Oceanic Islands. These are the Azores, Madeira, the Cape Verdes, St. Paul, Fernando Noronha, Ascension, St. Helena, Tristan da Cunha and Gough Island. In many ways they are the most interesting of all.

Looking again at Fig. 26, which shows the depths of the Atlantic, we see several areas of water which are less than 1,000 fathoms in depth and which are quite detached from the continental shelf. Two of these are situated on the Central Atlantic Rise and one is situated on the West African shelf. The Azores (Fig. 31) are the most elevated parts of the area of shallow ocean bed which lies approximately in latitudes about 34° to 36° N. The area which lies near the Equator carries St. Paul and that which lies out from the coast of Africa in latitudes about 15° to 20° carries the Cape Verde Islands. The other oceanic islands are situated on the rise itself, or on the adjacent ocean bed. Little zones of shallow water lie round each of them, but we do not speak of these as "continental" shelf since the deposition of materials derived from extensive continental land regions obviously does not proceed there.

Oceanic islands are composed of volcanic materials. The exceptions to this statement may have deep interest and significance in our study of the history of the oceans, but just now we only note that so many of the islands of the world that rise out of the deep ocean bed are volcanic in nature that we can make the above general statement.

The interest of the conclusion is this: we know absolutely nothing, from direct observation, of the nature of the rock that forms the ocean bed: all we know is that this rock, whatever it may be, is covered with semi-liquid ooze derived from the remains of microscopic plants and animals that live in the ocean. Now here and

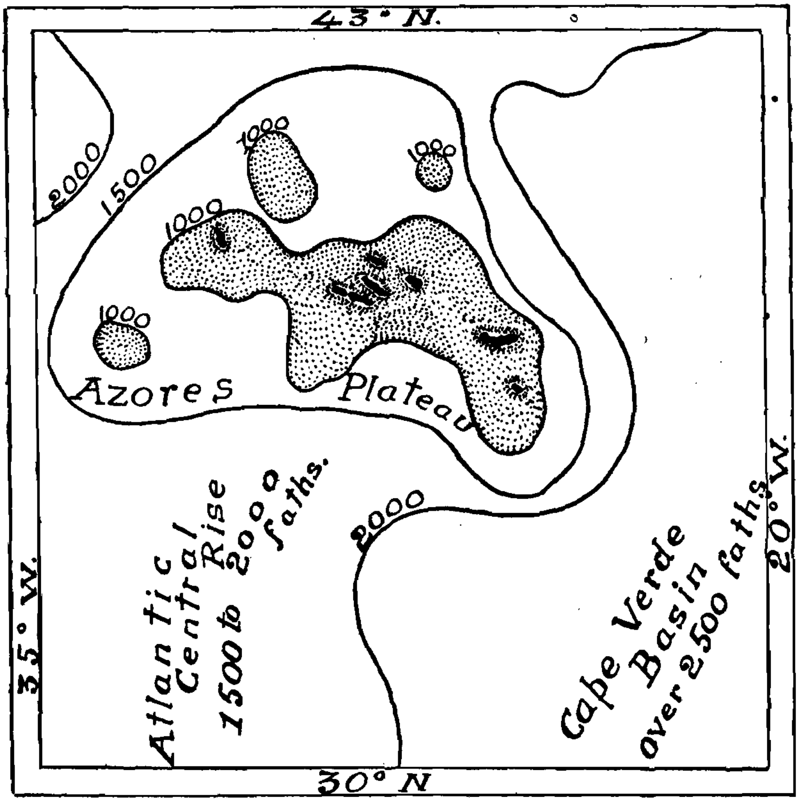


FIG. 31.—Oceanic Islands. The Azores Group, showing the Plateau of Ancient Continental Shelf.

there are low elevations or mounds of the ocean floor and the summits of these elevations just show above sea-level as oceanic islands. If these exposed parts are so very often volcanic in nature, then it seems reasonable to suppose that the parts of the ocean bed out of which they rise are also composed of the same kind of rock.

Now looking again at Fig. 31 we see that the Azores Archipelago is situated on the wide, northern part of the Central Atlantic Rise

not far from the region where the rise passes into the North Atlantic shelf that lies south from Greenland and Iceland. Assuming that the whole North Atlantic region was once continental land, which foundered at about the end of the Mesozoic period, we seem justified in regarding the Azores submarine plateau as part of this ancient land, and in looking at the present islands as the most elevated parts —those that were originally so high as to escape total submergence.

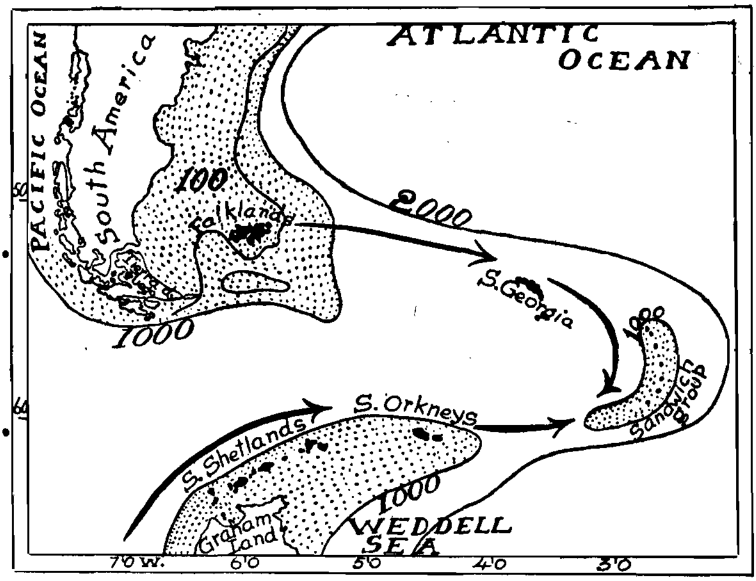


FIG. 32.—The Southern Region of the Atlantic Ocean, showing the Antarctic Insular Arc.

Islands of the arc are shown in black. The region of continental shelf is stippled. The curves with arrow-heads show the direction of the arc.

This also may be said of the Cape Verde Islands and perhaps also of Madeira.

The Canary Islands and Madeira. As we have already suggested these islands are those known to the ancient poets and geographers as the *Insulæ Fortunatæ*. At all times their climate and natural products have been such as to deserve the old name of the Fortunate Islands. They have been discovered so often in the period of which we have records that we may assume, with much probability, that they were found and colonized again and again in the remote past. They are (except Madeira) shelf islands, at no great distance from the Straits of the Columns, easily visited by bold navigators of small

vessels and possibly found again and again by sailors and fishermen who were blown out of their courses. To the shipwrecked mariner they must have been, indeed, fortunate landfalls, and one may well imagine Phœnician and Grecian voyagers landing there after severe trials at sea, settling down to eat the lotus fruits, and in the end feeling the discontent of inaction and straggling back to the civilized world again. Then, after the return to the artificial life of cities and polities had lost its freshness, they would think of the Fortunate Islands like we all exaggerate past delights. They would speak about these past felicities and so would grow up the legend of the Islands of the Blessed.

The Lost Atlantis

In one of his Dialogues, the *Timœus*, Plato tells about the legend of the ancient lost civilization of the land of Atlantis. It is an Egyptian priest that speaks to Socrates about this ancient land that existed 9,000 years before the time at which the philosopher was writing. Out to the west of the Pillars of Hercules, beyond the ocean, there was a land which was as big as both Europe and Africa (note that only a small part of Africa was then known) and it was the seat of an old civilization. The climate was mild and the natural products of Atlantis were such as to make agriculture an easy task. The people were wise and virtuous and their rulers had all the qualities that seemed desirable—even to Plato. But they became warlike and aimed at setting up an empire. So one of their armies came to Europe and even approached Athens, when the Greeks, after a great struggle, repelled these invaders from over the ocean. The danger passed for the time, but it came again, and the Atlantides accumulated a great force of men and materials and despatched these to Europe. Then, while the fleets were being expected back again, the great catastrophe came. Earthquake and volcanic eruptions took place on a scale never before experienced and in one day and one night Atlantis was swallowed up by the ocean. There remained only the muddy waters and the rocks and shoals and the sluggish sea to frighten all the navigators who thought about venturing to sail the Western ocean until the time of Columbus.

Now it has been said that Plato invented the legend of Atlantis in order to make a material framework for his speculations upon what form of government would be adopted by men who were actuated only by the desire to be virtuous and who were guided only by pure

reason and by the wish to please the gods. Such polities might exist, for a time, but in the end human nature would reassert itself. The civilization would become corrupt and would develop the tendencies that would lead to its destruction. So, forgetting the gods in their love of wealth and their ambition for empire, the Atlantides reached out for what was denied to them and then the wrathful gods destroyed their civilization. That the Dialogues have such a lesson as this is certain; Plato's main object was to expound it and he used a legend for this purpose just as, long afterwards, Bacon founded his Utopian State—the New Atlantis—with its House of Solomon, on the same imagining.

Yet there must have been a legend of a land that existed, long before the classical period, in the region beyond the ocean, and some of the excellencies of the Fortunate Islands were transferred to the legendary Atlantis—and to its inhabitants. It is, of course, quite impossible to reconstruct this barely remembered legend, still less to trace out the actual events which gave rise to it. One must never forget how very difficult it is for the human mind really to *invent* anything: elaboration of some pre-existing idea is difficult enough, but it is always being done. The actual creation of a new idea is, however, the most exceptional thing, as the history of every scientific investigation (or the analysis of the plot of any work of fiction) show. In the cases of all such traditions as that of the lost Atlantic continent we ought to search for some basis of actual occurrence which underlies the legend. It is interesting—and really quite instructive—to do so, even in a scientific treatise.

Cycles of Civilization. Now in the Atlantis tradition there is this ingredient: long ago in the past there was a great civilization that developed, flourished, became decadent and disappeared. We can easily verify this. Our industrial-scientific civilization is only the latest of some half-dozen of which we have actual records. That the basis of this civilization of ours is a scientific knowledge of nature which has enabled us to exploit accumulations of natural energy (coal and oil) does not give it any higher status than those of past civilizations—it is only different, for we can imagine (and we really know) human polities in which the characteristic feature of the industrial-scientific state was quite undeveloped. So we have the last cycle before ours, that of the classical Mediterranean civilization, which attained its climax during the fourth and fifth centuries B.C. and became thoroughly decadent during the fifth to the twelfth

centuries A.D. Before the classic Greeks we have the predatory, barbarous Greeks, or their precursors, who wrecked the last Cretan City States, just as that succeeded to a previous one which replaced the earliest Minoan civilization, which itself only came after still earlier Egyptian civilizations. Each went under by reason of its inherent defects and contradictions and the end came after some new blend or admixture of human races which conferred greater vigour on a conquering people (the Gothic invaders of Italy, at a later period, for instance). Of the qualities of these bygone States we can judge only by the few things which they left that were capable of enduring—buildings of stone, carvings in stone, pottery and so on. So far as these remains go they certainly suggest that one civilization has developed, become great, become decadent, and then disappeared to give rise to another one. Before the Greek classical civilization there was, therefore, an earlier one, and the tradition of this is one ingredient in the notion of the lost Atlantis.

The historic States developed in the region of the Mediterranean Sea—in Egypt, Crete and Greece—but the legendary civilization of Plato's Dialogue was an Atlantic one: it came from over the ocean. Now this may only be so because it was the practice of the Greeks to place all mysterious and legendary things on, or beyond the ocean. There they put not only the Elysian Fields, the Islands of the Blessed, the Gardens of the Hesperides, but also the entrance to the Infernal Regions. This explanation is satisfactory, *still* we have the hypothesis (well based on geological evidence) that it was in the North Atlantic Ocean that a great continental land subsided beneath the surface of the sea. This subsidence, was, probably, not quite complete, for it left behind it the Islands of the Azores. It is true that the North Atlantic continent foundered about the end of the Mesozoic period, not only long before the first appearance of man on the earth, but also not very long (in the geological measure of time) after the mammals themselves had assumed the form with which we are familiar. The legend of the Atlantides cannot therefore be a memory of the disappearance of the Atlantis of the geologists.

But we have the Azores as the remnants of the Mesozoic North Atlantic continent and it is quite *possible* that near them may have been other islands which were slowly subsiding and which disappeared, perhaps catastrophically, during the human period. This is, of course, a pure conjecture, but it is one which is consonant with what we do know of the geology of the North Atlantic ocean bed.

Presently we shall see that this is a region of marked earth disturbance. It may be that between the Azores and the Fortunate Isles there were other islands now submerged, and which were indeed peopled by men who were civilized. From these lost islands of the Atlantic the earliest inhabitants of the Canaries may have come—or *vice versa*, prehistoric man may have migrated out *viâ* the Canaries to islands in the ocean that no longer exist and there, in a hospitable and genial environment, developed a civilization which earth-catastrophism destroyed.[1]

Prehistoric Civilizations. Now it is again curious that we can reach back, far beyond recorded history, to something which we may reasonably call civilization. At a period which cannot be less than about 25,000 years B.C., and which may have been more than that, European man had reached a rather high stage of *culture*. He buried his dead with ceremony, so that he had the notion of personal immortality. He lived, how we do not know, but he certainly frequented caves, and in these have been discovered paintings in monochrome, or in four colours, incised drawings and sculptures—all on the walls of the caves. These drawings and sculptures are what *we* call works of art. Along with them have been discovered statuettes, carved staffs and batons, remains that are suggestive of a ritual of some kind. The men themselves are known to us by their skeletons and these show that Magdalenian and Aurignacian man—the " Cro-Magnons "—were physically superior to the present European stock. Their brains, for instance, were bigger than that of our own race. Quite evidently European man in France, Spain and in Britain had at this remote period attained to a rather high level of physical development and had also reached a state of culture which is revealed to us only by a few (literally) imperishable works of art.

The Aboriginal Inhabitants of the Fortunate Islands. It is impossible to be sure who these were. When the islands became first known to the Portuguese and Spaniards they were peopled, but antiquarian research was not in the programme of these adventurers and much has perished with the Conquistadores—in Mexico and Peru, as well as in the Canary Islands and Madeira. In our own time the islands are mainly peopled by Berbers—that is, European

[1] This is no more incredible than that early man should have migrated out over the entire Pacific Ocean islands. Yet this actually occurred before the historic period.

man of African, Hamitic stock, but it appears that there was an aboriginal race called the Guanches. These men lived in caves under the rule of patriarchs. They held communal property: they made carvings on the walls of the caves. They were tall men of a peculiar type which resembled that of the Cro-Magnons, with a long face which was, nevertheless, wide across the temples. Now the suggestion has been made—and it is not improbable, though, of course, there is no positive evidence to support it—that Cro-Magnon man survived in Europe in our own times as the Guanches of the Fortunate Isles. (He survives, still, as isolated individuals in Europe.)

It is, therefore, a permissible speculation to regard the Azores, with the Fortunate Islands and the Cape Verdes, as the last remains of the North Atlantic Mesozoic continent. Besides them there may have been others which underwent subsidence in early prehistoric times. The vague tradition of these lost lands may have come down to us as the legend of the lost Atlantis.

The Geological History of the Atlantic Ocean

First we may glance at the nature of the Atlantic coastal margins. We have three main kinds: (1) the general coastal lands of North and South America and Europe, (2) the West Indian region, and (3) the African coast.

(1) Fig. 33 represents those features of the Atlantic land margins that are ot general interest to us: there are two kinds of coast —*longitudinal* and *transverse* ones. When we consider the forms of Pacific coast we shall see the longitudinal type in great clearness: it is constituted by great series of earth-folds caused by horizontal pressures, and these folds run roughly parallel to the coast-line. They are elevated to form mountain ranges, the flanks of which are composed of the folded strata while the cores are made up of igneous rock. Now nowhere on the margins of the Atlantic Ocean do we see these longitudinal earth-folds so well displayed as they are on the east coast of the Pacific Ocean.

On the Brazilian coast, from the Rio Grande to about Cape San Roque, they are just indicated. Here we have lines of sierras running parallel to the oceanic margin. Then, on the east coast of North America, there are similar formations, represented by the Appalachian Mountains: these also run parallel to the coast from Florida to Newfoundland and Cape Breton Island. On the European side there are great earth-folds running down the coast of

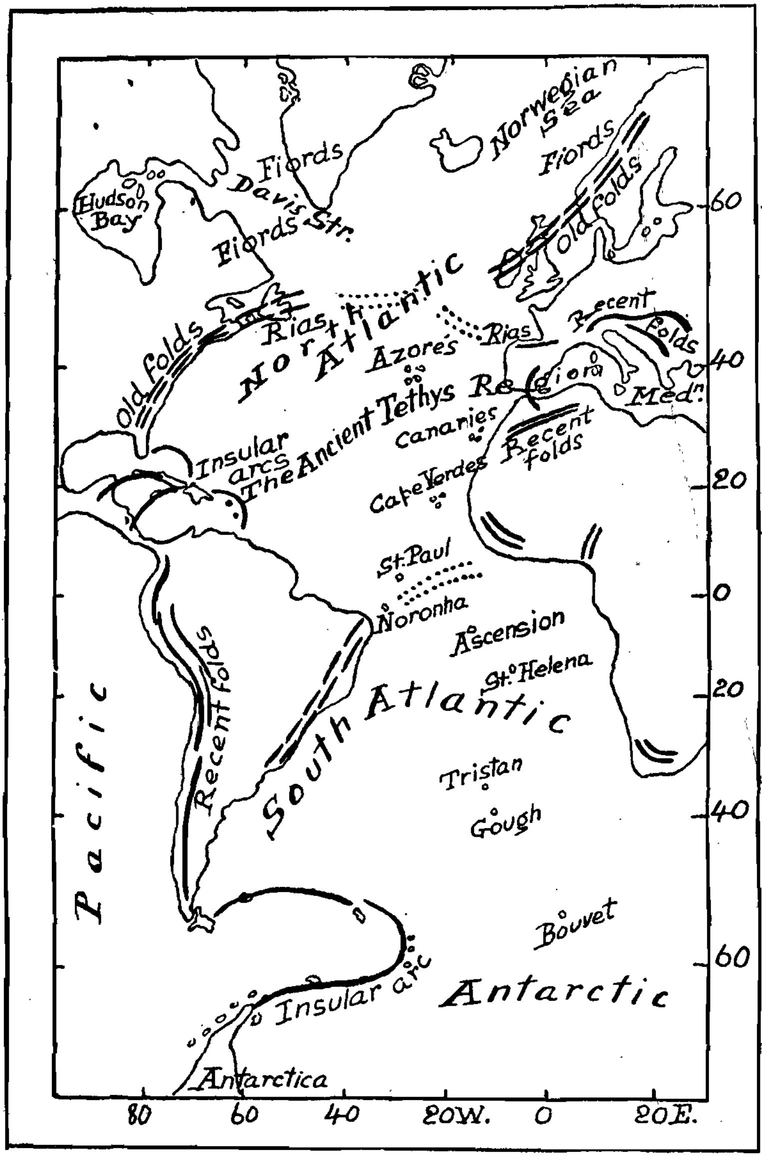


FIG. 33.—The Structure of the Shores of the Atlantic.

The curved lines drawn on the land surfaces represent the directions of the great earth-folds. The dotted lines show the directions of old earth-folds.

Scandinavia and reappearing in Scotland, across which they run from about north-east to south-west, as the Grampian ranges. Finally a short, curved earth-fold appears to enclose the entrance to the Mediterranean: this is constituted by the sierras in Granada, which curve round across the Straits of Gibraltar and become continuous with the coastal ranges in Northern Morocco.

All these longitudinal earth-folds *are old ones*, mainly of Mesozoic age. They are greatly eroded, particularly those of the North Atlantic, where their materials are spread out in the extensive regions of continental shelf.

Fig. 33 also indicates the other kind of Atlantic coast—the transverse type. Here we have the earth-folds, with deep fiords and shallow and wide valleys running into the ocean at angles approximating to 90°. Among the bigger formations of the type are the Appalachian mountain ranges, which dip down beneath the Atlantic in Cape Breton Island and Newfoundland. The ridges are the remains of the foldings and the drowned valleys between the ridges are called *Rias*. These widen and deepen as we go down them from the land towards the sea. We have here a series of foldings which have become tilted downwards below the surface of the ocean, into which they run at a high angle. Such folds entering the ocean in this way are also seen on the African coast—the Atlas Mountains and some other transverse formations in the region of the Bight of Benin.

On the west coasts of Scotland and Greenland are somewhat similar depressions entering the sea at high angles: these are *fiords*. Fiords are also drowned-out valleys lying between folds, but they differ notably from the Rias in that they have been filled with land-ice in the past (or at present, in the case of the Greenland fiords). The ice, moving through the valleys, has scoured out and deepened the bottoms, but has left deposits of material at the seaward ends (where the ice melted on its entrance into the ocean). Thus a fiord is a long, rather narrow valley filled with sea and which is shallow at its entrance and often rather deep as it passes up into the land. On the Scandinavian coast the fiords tend to run perpendicularly to the general direction of the eroded earth-folds, which themselves run parallel to the coast-line.

(2) The West Indian region (Fig. 30) is quite different from those which we have just been considering. Here we see great earth-folds rising up from the ocean bottom so that their most elevated parts

appear above sea-level as strung-out islands. These are the insular arcs and they represent parts of the ocean floor on the continental-oceanic margins where there is instability and where great movements are in active progress. Such movements, leading to earth-folding and to the appearance of mountain ranges, occurred in the past on the east and west margins of the North Atlantic, but these regions have long been stable ones. The movements have ceased and the mountain ranges resulting from the processes of folding and elevation are in process of erosion and are already greatly worn. In the West Indian region, however, the processes are in active operation and we see some of their evidences in the shape of earthquake and volcanic phenomena.

(3) Africa differs most strikingly from both the American and European continents. In the coastal regions of the latter there are, or have been, great horizontal pressures leading to the appearance of earth-folds which have been placed roughly parallel to the coastal lines. In Africa, however, these thrusting pressures have been strongly resisted and there is complete absence of the characteristic coastal mountain-foldings on the greater part of the continental margin. What we have in Africa are great blocks, or tablelands, marked out by lines of faults.

The Ancient Atlantic. It is not possible to reconstruct, in any detail, the past form and extent of the Atlantic Ocean, but when we consider the present distribution of animals and plants as well as that of the past, as indicated by their fossil remains, we seem to be forced to a certain configuration of land and water. We have to account for the existence, on both sides of the ocean, of many species of marine organisms that are unable to migrate across such extensive, abysmal regions as the present Atlantics, and which can only live and reproduce in shallow water near the land. Therefore we suppose that there was always continuous sea, bordered by shallow continental shelf, extending across in sub-tropical latitude : this was the ancient sea of Tethys which has always existed in geological times. It had land to north and south and shallow shelf regions, along which the shallow-water organisms could migrate and so distribute themselves on what are now the east and west margins of the Atlantic. Fig. 42 shows the ancient Tethys in Paleozoic (Devonian) and Early Tertiary periods (see p. 206).

Then land animals and plants must also have been able to distribute themselves on both sides of the ocean and so we suppose the

existence, in the past, of continuous land connecting the Old and New Worlds across the present Atlantic depression. That is, there were both North and South Atlantic continents, joining North America with Europe to the north of Tethys, and South America with Africa to the south. Between North Atlantis and South Atlantis lay the relatively narrow Sea of Tethys. Fig. 42 shows the probable distribution of land and water in the Paleozoic era, when the southern continent had its greatest extension. This was the ancient equatorial continent which included South America, Africa, and Australia and which occupied the regions of the South Atlantic and Indian Oceans.

Sometime in the Mesozoic era the process of submergence of a great part of this equatorial continent took place, and in the Late Tertiary era the North Atlantic continent foundered. The conclusion that the Appalachian Mountains extended across the ocean, from the Cape Breton Island region to Scandinavia or Southern Europe, seems very probable. Thus the Rias of the former region represent the ends of the Mesozoic mountain ranges as they dip down into the ocean bed, to reappear on the other side as the ancient Caledonian mountain system. Probably there was, at a certain phase in the great series of earth changes, a continuous North Atlantic geosyncline, somewhat similar to that which, we shall see, surrounds the Pacific Ocean. As to the cause of the submergence beneath the ocean of such extensive regions of continental land, we can only speculate in a rather unsatisfactory way, but it is quite probable that actual increase of water on the surface of the earth during the Mesozoic period may be one, and perhaps the main factor.

CHAPTER VI

THE PACIFIC OCEAN

We have dealt summarily with the history of geographical exploration of the Pacific region in Chapter III: that history was nearly completed when Bass and Flinders finished their survey of the Australian coast-line, early in the nineteenth century, and for the next hundred years the Pacific was the subject of detailed hydrographic investigation, together with biological and oceanographic research. These results are of the greatest possible interest and we propose to give a rough outline of them in this chapter. First of all, however, it will be useful to consider very briefly the history of the human populations of the Pacific shores and islands.

In the following chapter we shall have something to say as to the Phœnician voyages across the Indian Ocean and then into the Pacific itself. Long before Balboa stood on his " peak in Darien," and saw the great sea of the south, Semitic sailor-traders had sailed its waters. But long before that still it is fairly certain that men from the Old World had passed through the Straits of Malacca and had sailed on from island to island across the great ocean, perhaps even to the western shore of Central America.

Peoples of the Pacific Region

We do not know who were the first human races that inhabited the Pacific continental shores, but it may be conjectured, at least, that very early in the history of mankind primitive stocks had settled there. It is curious that the earliest record of man has been found in Java, in the shape of the skull and thigh-bones of the long-extinct *Pithecanthropus erectus*. In all probability man originated somewhere in Southern Asia and the occurrence of the " Ape Man " in Java suggests that his earliest migrations were not towards the Mediterranean but eastwards towards the Australasian regions. Then there was the migration that peopled Australia with its peculiarly low, aboriginal, pre-Dravidian stock, which still exists.

In these people, with the more highly evolved Tasmanians that were exterminated during the middle period of the nineteenth century, we have the nearest relatives, in strictly modern times, of the men of the Old Stone Age.

It is probable that after the aboriginal Australian and Tasmanian came those stocks that we call the negroids and oceanic negroids. These are not the same as the typical negro, Bantu peoples that are now found over much of Africa, and they must have spread from Asia towards the Pacific Islands about the same time that the true negro stocks were peopling Africa. They entered the East Indian region, that is Java, Sumatra, Borneo, New Guinea and the crowd of islands that we call Melanesia. From there they passed north towards the Philippines. About here the oceanic negroid peoples meet with the Mongols. These peoples probably differentiated themselves from the primitive stock of "modern man" ("modern" as opposed to "ancient man") contemporaneously with the negroid, negro and Indo-European branches, but later than the aboriginal Australians and Tasmanians, and they spread mainly to the east and north-east into the countries which we now call China and Japan. Probably they migrated further north into Siberia and thence to Lapland, Greenland, and the Arctic Archipelago. They may have crossed the North Atlantic, from island to island, ages before the Vikings found Iceland and Greenland and reached America from the east. It is more probable, however, that they journeyed round the north-west shore of the Pacific and crossed Behring Straits into North America, for there seems to be little doubt that the aboriginal American Indians, all over both continents, have come from Mongolian stocks, or from a race that evolved from the same stock as that which gave origin to the Mongolian peoples.

Thus in the South-west Pacific region we have the very primitive Australian peoples; round this, in the Melanesian Islands, the oceanic negroes and negritoes; to the north, the oceanic Mongols; on the western continental shores the Southern Mongols; in the far north the Northern Mongols; and on the eastern or American side the peculiar stock with strong Mongolian affinities that were aboriginal there when the Spanish and Portuguese landed. But, in addition to all these, there is another Pacific people of still greater interest—the Indonesians.

If we draw a curved line on the Chart (see Fig. 34) passing immediately to the west of New Zealand, then between New Caledonia and

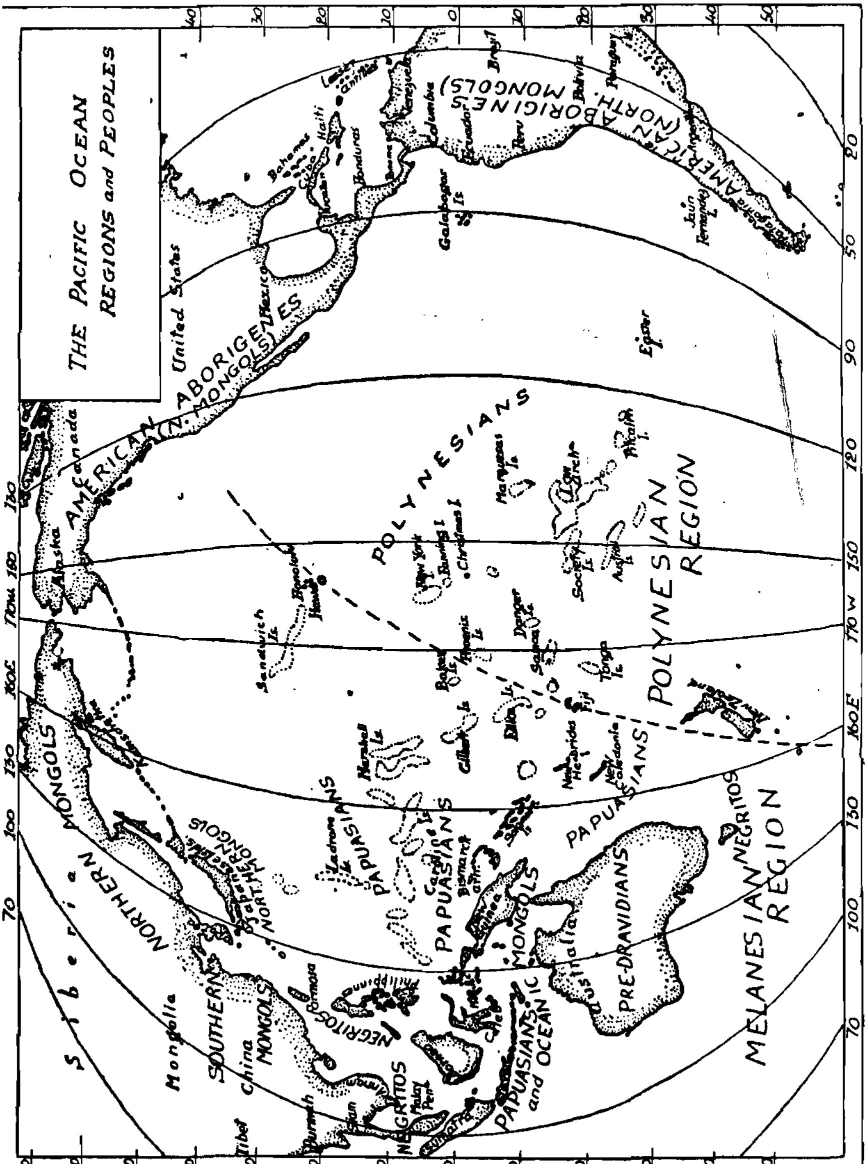


FIG. 34.—The Pacific Ocean, showing the Distribution of Human Races.

the Fijis, then passing to the east of the Solomon Islands, New Guinea, the Philippines and the Japanese Islands, we make a boundary that is both physical and ethnographical. On the south and west are Australia, Malaya, the Melanesian (East Indian) Islands, the Philippines and the Japanese Islands : on this side are pre-Dravidian, negroid and Mongolian stocks. On the east of the line are the Polynesian Archipelagoes (Oceania), inhabited by a people that differ remarkably from those that we have mentioned, both in regard to their physical character and their culture. These folks, the "South Sea Islanders," belong to the Indo-European branch of Modern Man[1] and it is now generally supposed that they came from the Valley of the Ganges, where they had settled, after a long previous history. They differ strongly from both the Melanesian and Mongolian stocks, but they also differ from the Gangetic peoples from whom they are supposed to have originated, and this latter difference points to a long history of settlement in the islands of the Pacific, during which period the characters and cultures which we now recognize became developed. At present they are the most entirely maritime people on the face of the earth.

How long ago it was that these Indonesian migrations occurred we do not know, but it is very probable that it was at least as early as the time of the formation of the great empires of the Indian oceanic region about which we have something to say in the next chapter. However, some of the cultures of the Pacific region are certainly of later date than this. It is certain that the Phœnician sailor-traders had traversed the whole extent of the Indian Ocean as early as 2000 B.C., and it is very probable that at least 1000 years B.C. they had entered the Pacific Ocean from the west. In Rhodesia and other parts of Africa there are very ancient ruins of stone buildings and somewhat similar remains exist buried in the forests of Central America. In Easter Island, in the eastern part of the Pacific Ocean, there are also peculiar remains in the form of gigantic monolithic statues, and it is quite probable that these mark the migration paths of a people who had crossed both the Indian and Pacific Oceans and established themselves on the American continent,

[1] "Modern Man" consists of one zoological species, *Homo sapiens*. There are several extinct species—*Pithecanthropus*, *Eoanthropus* (Piltdown man), Neanderthal man, and possibly some others. Modern Man is divided into the Indo-European (or Caucasian), Mongolian, Ethiopian, and Australian races.

leaving traces of their civilization at various points of their eastward migration route. We are to imagine the Phœnician galleys, with their slave-rowers, picked up here and there, being blown out into the Central Pacific, sometimes lost and at other times being cast away on islands inhabited by the Indonesian peoples. They would thus form settlements and become assimilated into the Indonesian stock in much the same way as the survivors of the mutiny of the *Bounty* were assimilated.

Of course much of this is conjecture, and it is now quite impossible to reconstruct the original migrations that peopled the Pacific regions. It will be enough to leave the student with a strong impression of the ancient character of this part of the world—from the humanistic point of view. We have here the very first traces of the human race in the unique Javan *Pithecanthropus;* the most primitive of human races in the aboriginal Australians; the complex mixtures of negroid and Mongolian stocks that inhabit Melanesia; the ancient and pure Mongolian races of China and Japan; the Caucasian element in the Polynesian population of the Central Pacific Islands with the traces of an old civilization; and lastly, the primitive Mongolian stocks of America where highly peculiar civilizations, like those of the Iriquois Indians, the Empires of Mexico and Peru, and the Maya cultures of Central America had had time to develop long before the Vikings and Columbus found their way west from Europe.

The Pacific Region in the Physical Sense

Fig. 1, F shows us the general aspect of the Pacific region as it is seen from outside the earth; here we simply have a "water hemisphere." But charts of the world such as those of Figs. 34, 35 and 36 emphasize the forms of the land margins rather than the ocean itself. These margins are arranged as follows: take a piece of string and, putting one end on Wrangel Island (just N. of Behring Strait) and the other on the Falkland Islands, stretch the string on the surface of a terrestrial globe. It will lie not far from the general trend of the Pacific American coast-line and it is a "geodesic," that is the trace on the surface of the earth of a plane passing through the two places mentioned and also the earth's centre.

Similarly the Asiatic Pacific margin lies near to another geodesic line passing through Behring Strait and the Malay Peninsula. Then we have still a third geodesic running from about New Zealand

to the Philippine Islands. These three geodesics enclose the Pacific except at the south, where it becomes confluent with the great southern ocean. The first and second that we have mentioned converge to the north, in Behring Strait, where the surface waters of the Pacific communicate with those of the Arctic Ocean.

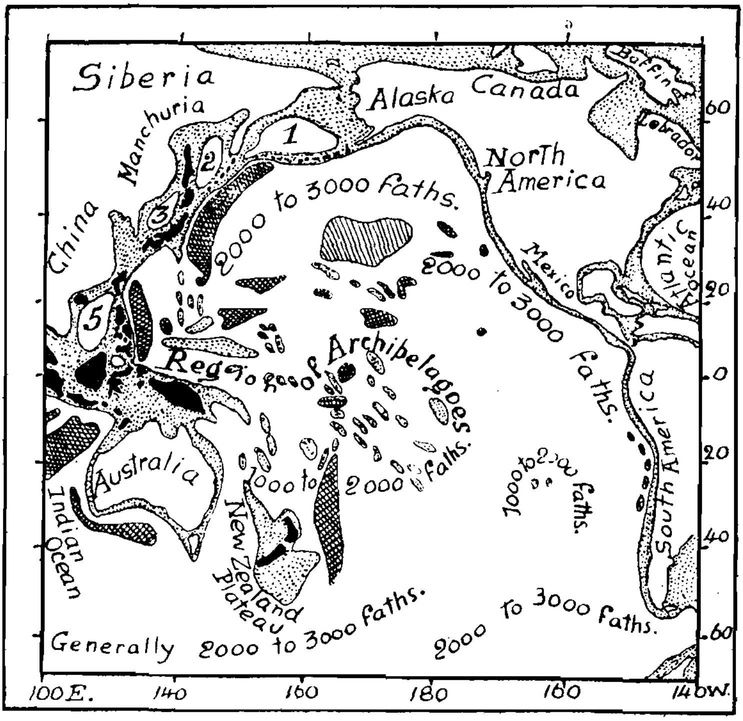


FIG. 35.—Sketch Chart of the Pacific Ocean.
The continental shelf region is stippled; the deeps (over 3,000 fathoms) are cross-hatched and the islands of the insular arcs are shown in black.

The American Margin. On the east we have the most remarkable coast-line in the world. Landward from the ocean margin there are great ranges of mountains extending from Tierra del Fuego to British Columbia—a length of 11,000 miles. These ranges are the Andes in South America; the Sierras of Central America and Mexico; the Cascade Mountains and the coast ranges of the United States, with the Rockies lying parallel to them. They rise, in places, to heights of over 20,000 feet. They run in long, gently curved lines with their convex sides turned towards the ocean.

Their flanks are composed of stratified rocks that have been folded, bent, contorted and even up-ended because of the immensely strong lateral thrusting pressures to which they have been subjected. In their cores are masses of igneous rock which have been intruded into them since the process of folding occurred. Seaward from these

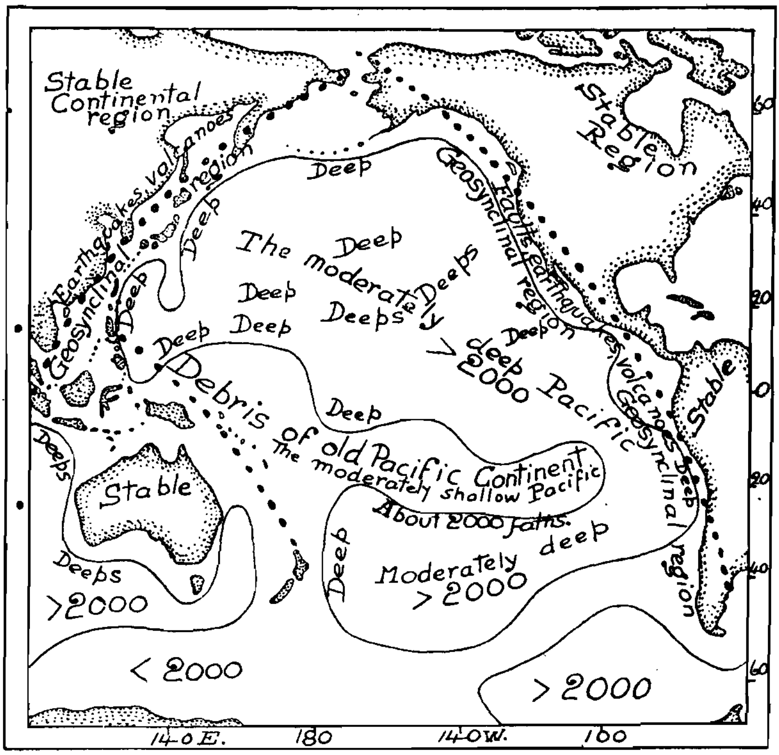


FIG. 36.—Structure of the Shores of the Pacific Ocean.

The dotted lines along the margins show the general courses of the geodesics. The contour line on the ocean follows roughly the 2,000-fathom line and is drawn so as to separate the deep and shallow regions of the ocean. The deeps are approximately indicated.

coastal mountain ranges the land slopes down gently toward the ocean. Then there is a narrow continental shelf and outside this the ocean bed goes down to depths of 2,000 to 3,000 fathoms. Off the coasts of Peru lie a series of "deeps," that is, long narrow troughs running parallel to the coast-line and having depths of over 3,000 fathoms. These troughs are called the "foredeeps" and they do not occur on the American side of the Pacific except just off the Peruvian coast.

This American Pacific coastal margin affords us the nearly perfect example of a great geosyncline—the continental land rising up into a series of elongated mountain ranges and then sinking down to great depths in the ocean. What it means we shall consider presently.

The Asiatic Margins. Here the conditions are, apparently, entirely different. Beginning with the North Pacific margin we see great numbers of islands situated well out from the continental land. These island groups are : Fig. 37 :

(1) *The Aleutians.* The Alaskan Peninsula runs out to the south-west and then there is a long string of islands which curve round to the west and end in the peninsula of Kamtchatka.

(2) *The Kuriles.* From the peninsula of Kamtchatka runs another string of islands, trending round to the west and ending in the Japanese island of Yezo.

(3) *The Japanese Group.* Sakhalin, Yezo and Hondo obviously curve round to the south and west and end in the peninsula of Korea.

(4) *The Lu-chu Archipelago.* This is constituted by a string of little islands which start out from Kiushiu, in the Japanese group, and end in Formosa. They run south-west.

(5) *The Philippines.* The eastern islands, Luzon, Samar, Leyte, Mindanao, and the little group called the Sulu Archipelago, form a string which curves round to south and west from Formosa to the north-east corner of Borneo.

(6) The western islands, Luzon, Mindanao and Palawan, run towards the northern promontory of Borneo.

Thus we have six archipelagoes situated well out from the Asiatic coast. In each case the separate islands are arranged in long, curved rows, the convexities of which face the ocean. Each group forms *an insular arc.*

The Melanesian Margin. A similar arrangement is indicated here. Thus :

(1) *Borneo* prolongs the Western Philippine arc towards the Malay Peninsula which curves round to the north.

(2) *Sumatra, Java, Floris, Timor,* etc., form a row which curves round (from Sumatra) to the south-east and east.

(3) *The Banda Group* consists of Timor Laut, the Arru Islands, Ceram, Buru and the Xulla Isles. These form the Banda arc.

(4) *New Guinea* is an arc in itself.

(5) *The Solomons, New Hebrides* and *New Caledonia* curve round from New Guinea to the south and west.

(6) *New Zealand.* The direction of the north and south islands, with that of the small ones lying to the south, suggest that the New Zealand group is also an arc. Between it and Australia lies a tongue of deep water.

The West Pacific Seas. Inside each of these West Pacific Island arcs lies a sea, and the insular arc, with its contained sea, forms a physical unit. These West Pacific seas are:

(1) *The Behring Sea* inside the Aleutian arc.

(2) *The Sea of Okhotsk* inside the Kurile arc.

(3) *The Sea of Japan* inside the Japanese arc.

(4) *The Yellow Sea* inside the Lu-chu arc.

(5) *The South China Sea* inside the Malay-Bornean-Western Philippine arc.

(6) *The Sulu Sea* between the Malay-Bornean-Western Philippine arcs and the outer Philippine arcs.

(7) *The Celebes Sea* between the Sulu and outer Philippine arcs.

(8) *The Java Sea* between the Javanese and Malay-Bornean arcs.

(9) *The Banda Sea* inside the Banda arc.

(10) *The Arafura Sea* between Australia and New Guinea.

(11) *The Coral Sea* between Australia and the Solomon-New Hebrides-New Caledonia arcs.

Fully to understand these very peculiar physical features we must now consider the depths off the East and West Pacific shores. Fig. 38 is an imaginary perpendicular section across the ocean in N. lat. 40°. In order to show the variations in depth on such a small scale the diagram is in two parts, the right-hand end of the upper segment being supposed to join on to the left-hand end of the lower segment. Also the scales are different, the horizontal one being about 1 mm. to 100 miles and the vertical one about 1 mm. to 200 fathoms. If horizontal and vertical scales were the same the diagram would be reduced to a very thin line of variable thickness.

Starting from the western side of the ocean we have, in order: continental land (Korea), continental shelf, epicontinental sea, insular arc (Japan in this case), foredeep, ocean bed, continental shelf, continental land (the United States). That is, there is the usual zone of shallow water of less than 1,000 fathoms off the Asiatic coast and then the bottom goes down, not to the ocean bed proper but to the bottom of an epicontinental sea which is nowhere greater than about 2,000 fathoms in depth. This sea is bounded by an insular arc and outside the latter there is no continental shelf

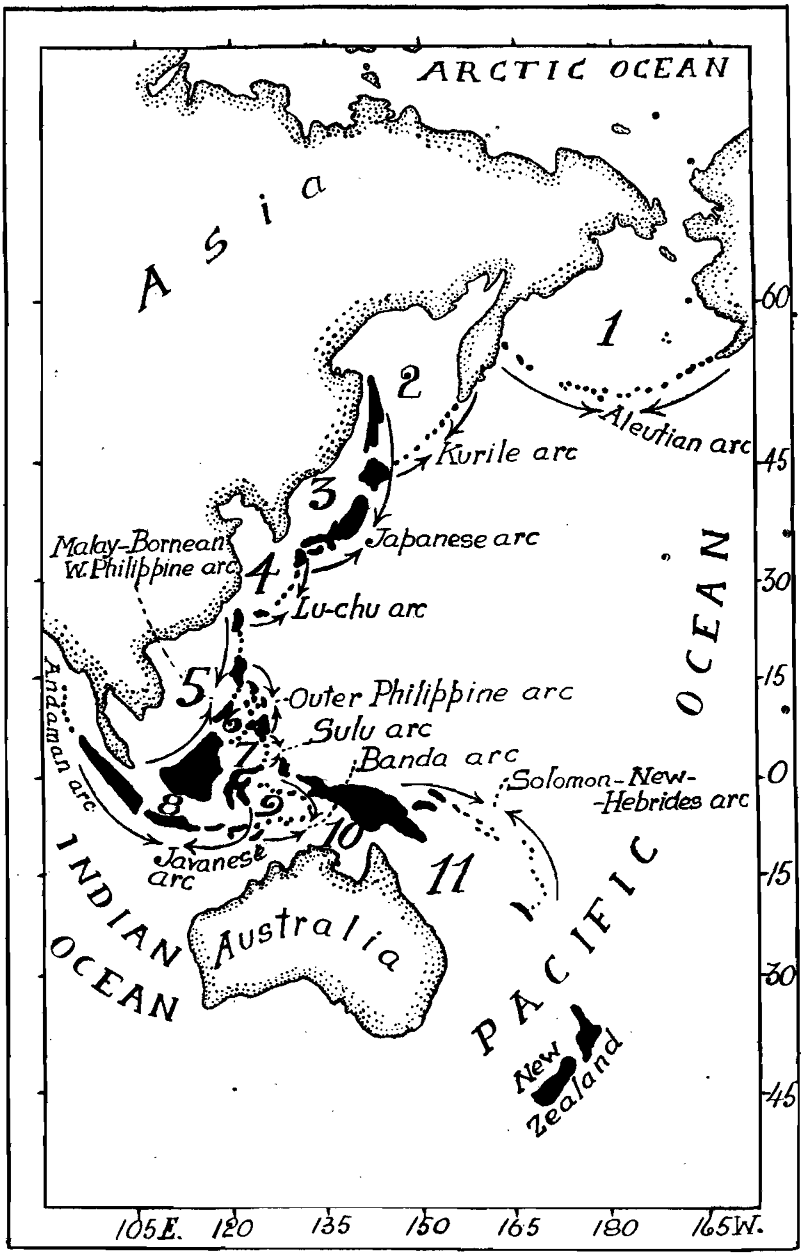


Fig. 37.—Islands and Seas of the West Pacific.

Islands of the insular arcs are black; numbers on the seas correspond with those on pp. 180–1, and the curves with arrow-heads show the directions of the arcs.

but the bottom descends to a depth (in the Tuscorora Deep) of over 5,000 fathoms. This is the foredeep, the elongated trough that lies

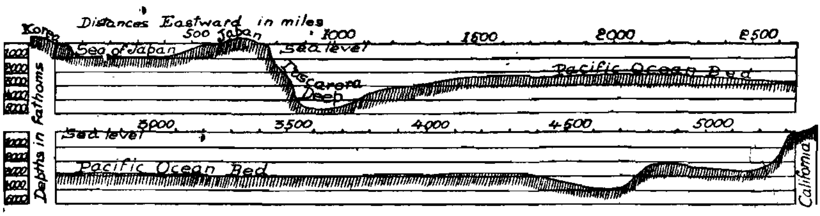


FIG. 38.—Section across the North Pacific approximately in latitude 40° N. The right-hand part of the upper figure should join on to the left-hand part of the lower figure.

(typically but not universally) outside an insular arc. Then we have the ocean bed, which is a good deal shallower than the foredeep (about 2,000 fathoms, on the average) and, on the American side, continental shelf again and continental land.

Scheme of Structure of the Pacific Regions

There is not, simply, a flat depression of the earth's surface filled up by the water of the ocean. On the east, which is simpler in structure than the western margin, we have an immensely long geosyncline marked out by a great series of earth-foldings which form the Pacific coastal mountain ranges. There has been lateral compression of the earth crust over the ocean bed. The underlying, cooling layers of the earth body have been contracting away from the crust, which, having cooled completely, has ceased to contract. But it must tend to gravitate downwards as the earth body shrinks away from it—that is, it tends to fall from a region of greater, to a region of less circumference, which is too small for it. Strains are set up which might be relieved if the crustal layer could become thicker, but this does not appear to be possible. There must, therefore, be enormous pressure exerted sideways and this has folded, contorted and crumpled and broken the marginal strata, throwing these into the form of earth-wrinkles running perpendicularly to the directions in which the lateral, thrusting pressure was exerted. Therefore we have the coastal mountain ranges.

Just the same has occurred on the Asiatic margin, but here the continental land has not undergone folding like the American land has done. In Australia and, apparently, in North-east Asia we have regions of earth crust that are very strong, so that they have resisted

the horizontal pressure from the ocean bed. It is, therefore, the submarine coastal strata that have been thrown into mountain ranges or earth-folds. These folds are mostly submarine and their most elevated parts appear above the surface of the ocean as the islands of the arcs. Why, exactly, the foldings occur at some distance from the continental land and why they take the forms of arcs cannot satisfactorily be explained. Even on the eastern side the mountain ranges are not one continuous chain, but tend to be represented by short, gently curved segments.

On the west of the Pacific there are, therefore, geosynclines just as on the east. On the latter margin is one nearly continuous geosyncline, but on the west there are a series, each being represented by an insular arc-folding, outside of which is a trough-like depression of the ocean bed. Inside each arc-folding a part of the ocean has been partly enclosed by the string of islands, and this is the epicontinental sea.

The Form of the Ocean Bed. Now another curious feature is to be noticed : The whole Pacific Ocean bed is not of a uniform depth and the variations take a certain arrangement over a considerable region lying between about 10° N. lat. and 20° S. The depth is mostly less than about 2,000 fathoms (though there are, of course, many deeper places) and there are extensive regions of archipelago. This central, relatively shallow part of the Pacific joins the Australian-Melanesian region, but it is separated from South America by water which is over 2,000 fathoms in depth. There is a distinct tendency for the deeps to take the forms of elongated depressions situated just off the coasts, and this is very obviously the case along the Asiatic margin, where the deepest parts in the whole ocean occur. These marginal deeps are not so apparent off the American coast, though a well-marked one lies out from the Peruvian continental shelf.

The Pacific Oceanic Islands. So far we have considered only the islands that form the insular arcs : these, we have seen, are the results of horizontal pressures which have folded the strata of an old sea bottom and raised this up as a ridge, the most elevated parts of which are the islands of the arcs. In the Pacific there are also oceanic islands, but they do not occur as isolated peaks, like they do in the Atlantic. Over the relatively shallow region of the Central Pacific these oceanic islands occur in great numbers and they are arranged in archipelagoes. Round the Australian-Melanesian region

there seems to be a tendency for the oceanic islands to run in irregular arcs—thus we have the Ladrones, the Carolines, and the series, Solomons-New Hebrides-New Caledonia. Generally, however, what we have in the Central Pacific are low mounds on the ocean bottom, and on these mounds elevated parts rise above sea-level as the oceanic islands.

The latter are mostly volcanic in nature—possibly consisting of the same kind of rock that forms the ocean bed. But a vast number of them are wholly or partially covered with coral rock and it is this feature that gives so much interest to the study of the Pacific Ocean. Coral islands occur in the Red Sea, Indian Ocean, and very exceptionally in the Atlantic (Bermuda is the only good example), but they are characteristic of the Pacific.

Coral rock is a massive, stony, calcareous formation which consists originally of the hard, bony skeletons formed by the animals that we call coral zooids, or polypes. These creatures have thus built up immense structures compared with which the greatest cities of the world are altogether insignificant. The coral skeletons compacted together with other materials form the great variety of coral islands and reefs.

Coral Animals. These are creatures that closely resemble the familiar sea-anemones of our own shores, but they have the character of forming a massive skeleton, in the form of a calcareous cup, in which the zooid dwells and from which partitions pass radially into the soft substance of the animal's body. They are colonial animals: thus they reproduce by budding and all the buds remain attached together so that their skeletons become confluent, forming a massive stony structure sticking up like a hummock from the sea bottom. The animals themselves have rather peculiar habits: they can only live and reproduce actively on sea bottom which is not more than about 20 fathoms in depth. They want clear water which is in continual agitation, which is well lighted by the sun (so that it must not be too deep), and the water must contain its usual quantities of oxygen and carbonic acid gas in solution. They feed in the same way as many other animals, by capturing and ingesting microscopic organisms that swim about in the water. But—a very important thing—they can also nourish themselves in the same way as ordinary green, red, and brown sea-weeds (algæ) do: that is, they can take carbonic acid gas from solution in the sea water and they can build up carbohydrate substance from this and incorporate it into the

living substance of their bodies. So where there are actively growing corals there is a curious absence of the seaweeds that are so characteristic a feature of our own rocky shores.

The Form of Coral Reefs. There are three main kinds in the Pacific: (1) Barrier Reefs, (2) Fringing Reefs, and (3) Atolls.

The best example of the first kind is *the* Great Australian Barrier Reef. This runs for about 1,000 miles outside the north-east coast of Australia. It has a width of about 10 to 30 miles and it rises nearly everywhere to very near sea-level, now and then actually showing above the latter as series of low, flat islands. It is, on the average, about 10 miles distant from the land, and between it and the Australian coast there is a channel with depths of about 10 to 30 fathoms. There are breaks in the barrier through which vessels can pass.

Fringing reefs are very like the barrier ones except that they lie much closer to the land (which is usually the shore of an island). Between them and the land there is generally a channel navigable for small boats.

Atolls are present where there is no visible land. The barriers and fringes cling to continental and island shores, but the atolls (and some other irregular forms of coral reefs) appear, so to speak, to rise up from the sea bottom on their own account. Typically an atoll is an incomplete ring of reef surrounding a very shallow sea, or lagoon. The ring may be of all sorts of shapes and it is sometimes many miles in diameter.

Inside an atoll, and between a barrier, or fringe, and the land there is always shallow water, only a few fathoms in depth. On the bottom of the channel, or lagoon, is living or dead coral rock. Outside the reef there is a narrow, flat and shallow terrace over which the seas break and outside this again the sea bottom descends much more steeply than it does anywhere else. The gradient may be as much as 1 in 10 to 1 in 2 and it goes down to the deep ocean bed.

Formation of Coral Reefs. The first hypothesis of coral reef formation that was generally accepted was that made by Charles Darwin. He showed that, in the Pacific Ocean, coral reefs were formed where the land was undergoing subsidence. He started with a volcanic island rising well above sea-level. Since the coral zooids can only reproduce on the sea bed under shallow water they would, at first, form a fringe of coral rock all round the island. How, then, would the channel between the fringing reef and the

shore be formed ? On the outside of the reef the sea water would be in violent motion so that the corals would grow there more rapidly than on the inner parts of the reef. By and by the seas would break away large blocks of coral rock as this came near to the surface, and this debris (dead coral rock) would be piled up on the top of the reef. The zooids on the inner part of the reef would die, so that growth of rock would cease. Fishes and many other marine animals eat and bore into coral rock because it contains much organic matter, and so the latter would disintegrate into mud. Seas and tides, breaking over the reef and running through the channel, would sweep away this loose coral debris. Thus the channel would form.

As the island subsided the channel would widen out and the reef would cease to be a fringing one and would become a barrier. Finally the island peak would disappear completely below sea-level. All the time the channel would be filling up to a certain level, after which the loose coral debris would be swept out. Then, when the island had completely disappeared, we should have a coral atoll and lagoon.

Darwin's theory was much criticized about the end of the nineteenth century. The great difficulty, to many people, was the assumption of subsidence on so vast a scale as that of the central region of the Pacific. Then it became known that there might actually be reefs in places where the sea bottom was undergoing elevation. A new theory was made by Murray to account for many kinds of reefs where subsidence could not be proved. It was thought that low mounds on the sea bottom might become raised up to near sea-level by the deposition of ooze on their summits. When they came up to about 20 fathoms or so from the surface coral zooids would begin to build on them. Again, alterations in sea-level, it was contended, might be the cause of reef formation. Suppose that a series of " ice-ages " existed in the past (in some ways quite a reasonable assumption). Then there would be a great increase in the magnitude of the polar ice-cap during the cold phases, and this means that liquid water would be withdrawn from the ocean and deposited on the polar regions (one or both). Thus the sea-level would fall by an amount estimated at about 30 fathoms. Wave action would then cut into the shores of continents and islands, forming sloping terraces and flat summits. When the warm phases came and the ice-caps partially melted water would be restored to the ocean and the sea-level would rise. Water would

then cover the sloping terraces and insular flats so that the coral zooids would begin to build there.

It is very probable that such alterations of sea-level are a competent cause of coral reef formation and they may have happened from other causes than alterations of climate. We saw in Chapter I that the earth's rotation has slowed down by about 4 hours during the geological period. As this happened the figure of the earth must have adjusted itself to the change in rotational speed, and the equatorial bulge must have become less. The plastic earth-interior would quickly and easily adjust itself, but not so readily would the strong earth crust yield. Strains would be set up and these would accumulate until, from time to time, the crust would yield, causing marked surface disturbances (mountain range formation, faulting, folding, etc.). But the ocean, being completely mobile, would yield at once. Probably there would be periods when the ocean level oscillated between the equatorial and polar regions (a suggestion due to Mr. Harold Jeffreys). This would have the same effect as the alterations of level due to climatic changes in the frigid zones.

But it is quite evident that we still require further investigations before we can make a complete theory of coral formations.

The Geological History of the Pacific Ocean

Now it is evident, from what has been said, that we cannot hold to the old notion of the permanence of the oceanic basins. (1) It seems very probable that great changes in the crust of the earth have been going on throughout geological time. These changes have come about at times of crisis, when the crust yielded to the strains that had been set up in it. Mountain formation then took place and it is very probable that the bed of the ocean was also affected. It seems that these crises have occurred some half-dozen times during the geological period. (2) It seems certain that the total volume of water on the surface of the earth has been increasing. As liquid rock has been extruded from the hot earth-interior to the surface it has set free enormous volumes of steam. Thus some parts of the ocean must have become deeper during the geological period. (3) It seems certain that we must assume the existence of former land connections between the continents in order to explain the distribution of land and shore plants and animals. It has been thought that such land bridges would be formed simply by connecting Asia and America across the Behring Strait, Tierra del Fuego

and Antarctica across the 600 miles of shallow southern ocean, and Africa and Antarctica across the same southern ocean. These changes would make a connected world admitting of land paths everywhere and they would leave the great oceanic basins much as they are now. But the very great differences in climate experienced in passing from, say, tropical Africa to tropical America *viâ* Antarctica would themselves be barriers to the migration of most organisms. So, although the connections of the continents, *viâ* the circumpolar regions, very probably existed in the past, they do not solve the problem unless we also assume corresponding climatic changes.

It has also been thought that the process of organic evolution may have gone on independently in various continents. Thus the very peculiar marsupial animals may have evolved independently both in Australia and South America. This *might* have been the case, but to assume that it was so brings us up against most formidable difficulties of a biological nature. On the whole it is much easier to assume continental land connections.

Now we have seen that while there appears to be geological evidence that continental lands have subsided to ocean-bed level, there is no evidence whatever that ocean beds have ever become dry land. Taken along with the hypothesis that the volume of the ocean has been increasing, this is suggestive : it allows us to speculate as to the existence of a past Pacific continent which has now subsided below ocean level.

The Pacific Ocean and the Moon. A distinguished geologist made the hypothesis that the present bed of the Pacific Ocean is really the scar left when the moon was formed from the earth. But this event must have happened long before the earth crust ever formed because it was due to violent resonant tides set up in the earth body. Even if it had happened when the first solid crust was in existence the " scar " left would not have endured for more than a matter of days or months.

Geology of the Pacific Ocean. Thus we seem compelled to reject the notion of oceanic permanence. We must also reject the hypothesis that the Pacific Ocean represents the " scar " left by the birth of the moon. We accept the theory of earth-cooling and contraction leading to phases of " diastrophism," that is, great disturbance of the earth's crust and movements of elevation of mountain ranges. We also accept the hypothesis that the volume of the ocean is increasing, so that it is getting deeper.

It is worth noting that reconstructions of the past distribution of land and water generally make both North and South Atlantic continents—about that geologists are agreed. Also a great tract of continental land is supposed to have joined Africa and India, through Madagascar and the Central Indian Ocean Archipelagoes. Some of the reconstructions show Central Pacific continental regions which foundered beneath the ocean in Early Tertiary times. All the reconstructions of past land and ocean agree in showing the great geosyncline surrounding the Pacific region.

Now the latter ocean bed must have been formed *some* time in the past, and since we reject the notion of oceanic permanence it does not follow that it was there at the beginning of geological history. We have seen that it is very probable that the Atlantic Ocean (or at least the temperate Atlantic regions) subsided in late Mesozoic times. It is quite evident that the Atlantic coasts are *older* than the Pacific ones (with an exception that we shall notice presently), for the old marginal mountain ranges are much eroded while volcanic and earthquake phenomena have quite ceased except near the equatorial Atlantic region. On the other hand the whole Pacific coastal lands are in a state of activity in the region of the great geosyncline. Volcanoes are active nearly all the way round the ocean and on the American and Asiatic margins earthquakes are frequent. On part of the Japanese geosyncline we have the most active earthquake regions in the world.

Therefore the Pacific coastal margins are in a state of dying-out diastrophism—that is, processes of mountain building by thrusting pressures that are causing earth-folds are or have been in operation. On the eastern margin these processes are now nearly complete. Volcanic and earthquake phenomena are not so prominent there as they are on the Asiatic side. The great geosyncline is in process of smoothing out and the deeps along the edges of the continental shelf are evidently filling up by the deposition of sediments. As these marginal deeps have filled up the earth's crust has become loaded and has been pressed down. Therefore isostatic compensation has been taking place; material from beneath the ocean bed has been flowing to underneath the continental land margin and the latter has been lifted up to form the great American Pacific mountain ranges.

The same processes have not yet gone so far on the Asiatic and Melanesian margins. There the thrusting, horizontal pressures have

produced one series of earth-foldings after another so that, in the whole West Indian region, we see " festoons " of insular arcs, each of these being a separate earth-fold. The inner ones have filled up—for we see indications of folds on the Asiatic land. The epicontinental seas (which are remnants of the *old* Pacific marginal ocean that has always existed in the geosynclinal region) are also filling up with sediments. But on the outer insular arcs the folding process is still at work and the evidences of this are the earthquake and volcanic phenomena, and the great deeps outside the arcuate folds. By and by the West Pacific epicontinental seas will fill up, or become such shallow-water regions as the North Sea, the Baltic and Hudson's Bay, and the Asiatic margin will take on much the same characters as the American one.

That the Central Pacific should be shallow relatively to the margins follows from Jeffrey's theory of contracting ocean beds. There is reason to believe that the latter are very strong (so that they do not easily become folded); that the hot earth-interior beneath them has cooled more rapidly than it has beneath the continental land. Therefore a whole ocean bed must actually *warp* downwards at its margins as it contracts on to the cooling interior. So we have the deeps at the edges of the ocean beds. When it proceeds so far, then contraction downwards must be relieved, and this has been happening in the Pacific-Asiatic margin. Great crackings or faulting have taken place, giving rise to the earthquakes that occur in this very disturbed zone.

This is what the whole Pacific region *looks like*—as we see it in Fig. 36. Australia dominates the whole south-western part—the land-mass being a great resistant buttress, or shield. The whole central part is relatively shallow, so that multitudes of islands appear above sea-level. Round this central region the ocean bed is tilted downwards to the north-east, north and west, and mainly to the north-east. The impression is that of a subsiding area, the process of subsidence being most marked round the margins. In Haug's view the Central Pacific Island region is the debris of an ancient Pacific continent.

Perhaps the central region has not actually subsided to such an extent as to transform a continental region into an ocean bed. There are great expanses of sea where the water is less than 1,000 fathoms deep (something corresponding to continental shelf, though not really such in the ordinary sense). On these shallow-water regions are

situated the archipelagoes. What probably existed there in, say, Mesozoic times was a great complex of slightly elevated land with extensive shallow seas. Some subsidence may have occurred over this entire region, but along with this there has probably been a gradual rise of sea-level due to the increase of water in the ocean. It will be seen that this explains the origin of coral reefs as well as does Darwin's original idea that an actual sinking down of ocean bottom had occurred.

We conclude, then, that there has been, for long periods of geological time, an extensive circum-Pacific geosynclinal zone occupied by deep ocean. Sometime early in the Tertiary Period the Central Pacific land became covered by ocean, partly as a result of subsidence and partly by an actual rise of sea-level.

CHAPTER VII

THE INDIAN OCEAN

The Human Races

Somewhere in Southern Asia, probably on the slopes of the great elevated plateaux extending east from Persia, the human species originated. That may have been several hundreds of thousands of years ago, for the tendency of present research is always to push back into the past the time of human origin. Some three or four distinct biological species of man probably came into existence: there were, at least, *Pithecanthropus*, Piltdown Man (*Eoanthropus*), and the Neanderthals, and all these became extinct long before the beginning of the historic period—say some ten thousands of years ago. About then there was only one species, Modern Man, and this had already differentiated into four groups. These were Australian Man, Ethiopian Man, the Mongolians and the Indo-Europeans. By this time the main migrations, leading to the dispersal of the human races, had been made (see Fig. 39).

Each of these categories includes a great number of races marked by physical differences, cultures and languages. The Indo-Europeans comprise not only many of the peoples that inhabit the Indian Peninsula and most of Europe, but also some of the Pacific Oceanic Islanders. Considering only the Indo-Europeans proper we can divide them into (1) the Nordics, (2) Mediterranean Man, and (3) the Alpine races. In each of these sub-categories there are again a number of sub-races, but the affinities are by no means clear and there is no recognized and general classification in use. We shall consider only Mediterranean Man. He came originally from somewhere north and east of the head of the Persian Gulf and, very early in his history, split into two great branches—the Hamites and the Semites. Now in the very earliest period of which we have any sure knowledge this separation was not very complete and we assume the existence of " Proto-Hamitic " and " Proto-Semitic "

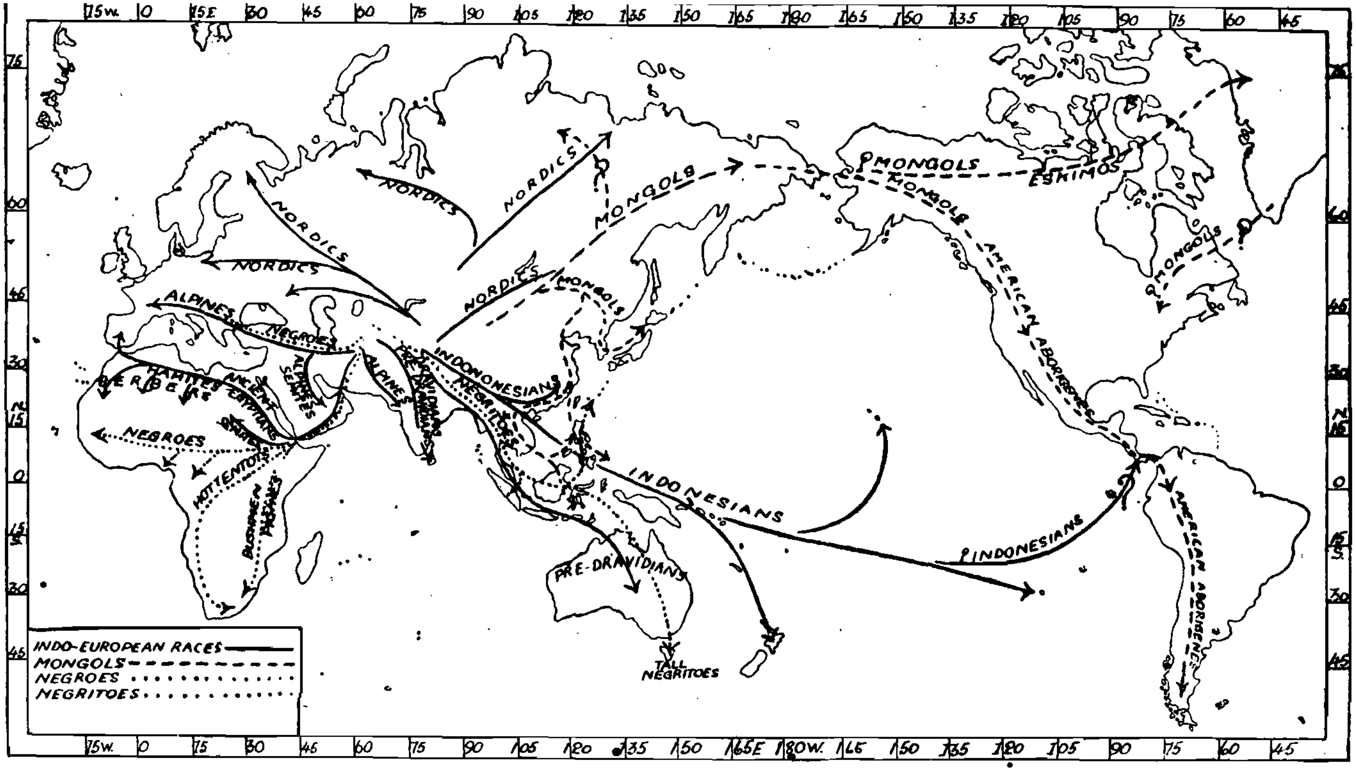


Fig. 39.—Main Paths of Dispersal of the Principal Human Races.

stocks which then differentiated into the peoples that we know. The Proto-Hamites gave rise to the Ancient Egyptians, the Nubians, Abyssinians, Somals, Masai, Berbers, etc., when they entered Africa and spread over its northern and eastern parts. The Proto-Semites gave rise to the peoples that established themselves in the region watered by the rivers Tigris and Euphrates and in those parts of the Arabian Peninsula that were then capable of supporting man. This is about as much as we know of the very early history of Mediterranean Man. Nordic Man spread to the west and north of Europe. The third great division of Caucasian Man—the Alpine races—seem to have clung mainly to the highlands bordering on the Mediterranean, but very early in history they appear as the Ancient Cretans, who built up a civilization in the Mediterranean, centring in the Island of Crete.

Early Civilizations. We are mainly interested with the origin of the first great ocean-faring races, but we must just glance at the history of the peoples who preceded these. At the very dawn of the historic period, then, we find a people, called the Sumerians, occupying the flat, fertile, Tigris-Euphrates region, building cities and establishing themselves there about 6000 to 5000 B.C. The Sumerians we may (rather loosely, it may be) call Proto-Semitic. Then came a series of invasions from the original home of the Semites proper—fertile Arabia. As the result of the first of these migrations the first Sumerian Empire was conquered by a monarch called Sargon about 3000 B.C. Later on a new Semitic migration established the Babylonian Empire—that was about 2000 B.C.—and later still, about 1100 B.C., a third Semitic movement conquered Babylonia and founded the Assyrian Empire.

There were contemporaneous civilizations in Egypt and Crete. The Ancient Egyptians appear in history about 6000 B.C. (but they had certainly formed polities long before that time). They occupied the narrow, fertile strip of North Africa watered by the Nile, the region of the Delta and the land across the isthmus towards the Gulf of Suez. Their influence probably extended much farther. We have reason to believe that they were not a sea-going people, yet they had large vessels on the Nile at least 2500 B.C. Probably they first associated with or employed the maritime Cretans, as latterly they employed the Phœnicians.

Thus there were overlapping civilizations during the ten thousand years before Christ and we may represent these by approximate dates :

Egypt.	*Crete.*	*Mesopotamia.*
0 to II Dynasty .	. . . . . .	1st Sumerians—6000–5000 B.C.
III to VI „ .	Early Cretans	„ „ —5000–4000 B.C.
VII to XIV „ .	Middle Cretans	1st Semitic Empire—4000–2600 B.C.
XV to XX „ .	Late Cretans .	Amorites, Assyrians—2600–1000 B.C.

In each of these four periods, from about 6000 to 1000 B.C. we can make out a cycle of civilization: a progress upward towards a climax, then a period of decadence, and lastly a crisis of downfall terminated by a conquest and sometimes a change of race.

The Rise of the Phœnicians. Unfortunately we know very little about the origin of this remarkable people who are so interesting to us in our enquiry into the beginnings of maritime enterprise. They were a Semitic race who had their origin in Arabia, but who had certainly established themselves on the shore of the Persian Gulf and Red Sea at least 2000 years before Christ. They used the sea even then, and at that period, when the third Cretan maritime civilization was falling, sea power passed into their hands. They migrated to the Red Sea and Mediterranean, and from then, until the time of maximum power of the Roman Republic, they "held the sea." The commerce of the Mediterranean and the external trade of Egypt was carried on by them. Certainly in the period 2500 to 1500 B.C. they used quite large vessels propelled partly by oars and partly by sails, and it is certain that a long period of evolution must have preceded this phase. About 2000 B.C. they had established ports at Tyre, Sidon and Acre, in the Mediterranean, and they had a port somewhere in the Red Sea. A little later they founded colonies on the north coast of Africa and they had also a port on the Atlantic—the Tartessus of classical writers, the Tarshish of the Bible, the classical Gades, and our Cadiz. Their great centre was, however, Carthage, which they colonized about 800 B.C. This became the centre of a naval and military power which rivalled that of Rome and of a commercial power which was even greater than that of Venice at her maximum. The rivalry with Rome ended when political and mercantile degeneracy, and reliance on a mercenary soldiery, had enfeebled the Carthaginians. The city was destroyed by Rome in

the year 146 B.C. and from then the Phœnicians, as a civilized people, passed out of existence.

The Phœnicians on the Ocean. Thus, in the period of which Homer writes, a period which, we used to think, was that of the very beginning of history, there was an ocean-going people with a long previous evolutionary history. At the time of Homer, say 1000 B.C., Solomon, King of Israel, was building his great temple at Jerusalem and he employed Hiram, King of Tyre, to bring to Palestine those materials which could not be obtained in that barren country. These Phœnician sailor-merchants brought timber from Mediterranean countries; silver from Burmah, Mashonaland and Ophir (Malaya); gold from Ophir; woods, fabrics, incense, peacocks, etc., from India and pearls from the Red Sea and Ceylon. But nearly 2000 years earlier still—in the Pyramid Age of Egypt—we find traces of the same extensive commerce. Sailors who appear to have been Phœnicians employed by the Egyptian monarchs went to the Syrian coast, to Somaliland, and to South Arabia to find the incense, spices, resins, wood, gold, gems, etc., that were necessary in the funerary rites and processes. That commerce meant either that the Phœnicians themselves visited the lands from whence these substances were obtained, or that they had trading connections with the "Arabs" who frequented the shores and ports of the Indian Ocean. Probably they both used the Arab vessels and traded on their own account.

These far-reaching trade routes (Fig. 40) led to a certain influence of the Phœnicians upon the native populations in Africa, on the shores of the Indian Ocean, and even in Polynesia and America. Such traces of Semitic and Hamitic culture are to be seen in the terraced agriculture, the stone buildings and pyramids, megalithic statues, customs of mummification, worship of the sun and sky-world, etc., that we deduce in Mashonaland, in Rhodesia, the Transvaal, in Easter Island (in the Pacific) and in Central America. This assumes that the Phœnicians in the period between the Pyramid Age in Egypt and the last few centuries B.C. had traversed the whole coasts of Africa and the Indian Ocean and had even crossed the Pacific Ocean after passing the Straits of Malacca. This crossing of the Pacific may have been involuntary, vessels being swept out by storms into the ocean and then caught up in one or other of the great current-systems. Or it may have been voluntary, for there is no reason to suppose that these ancient mariner-traders were any less

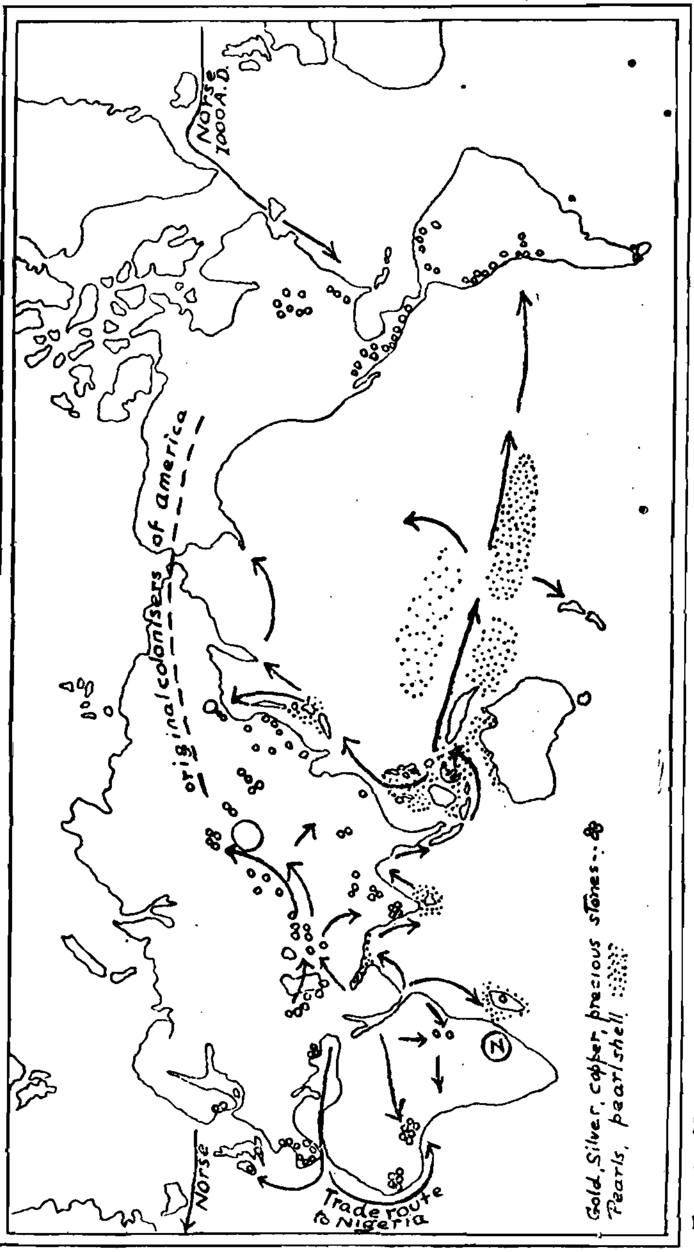


FIG. 40.—Main Trade Routes of the Phœnician Sailors. The Mongol and Viking Connections with the American Civilization are also indicated.

venturesome or skilful than were the Portuguese that slowly felt their way down the west coast of Africa and entered the Indian Ocean, in the fifteenth century A.D. In the course of these ancient sea passages the Phœnicians became greatly intermixed with the native populations—Ethiopian, Malay, "Arab," Negrito, etc. Thus we account for the traits of Mediterranean and Armenoid man among the Polynesians.

The Phœnician Circumnavigation of Africa. So, during the period when the Greeks were rapidly attaining a knowledge of scientific geography, the Phœnicians were boldly crossing the oceans and traversing the coasts of the eastern world in search of commodities with which to trade with the Mediterranean countries. Real indications of such voyages are not wanting. There is the account given by Herodotus of the circumnavigation of Africa from the east, during the reign of Necho, an Egyptian monarch who flourished in the period 610–594 B.C. Sometime about then there was an ancient canal cutting through the Delta from the easternmost branch of the Nile to the Gulf of Suez. Necho had also a port on the Red Sea, the remains of which were seen by Herodotus, and he had there a fleet of trireme vessels, doubtless manned by the Phœnicians and their slave oarsmen. He sent a fleet of vessels from the Red Sea to the south of Africa, a quite possible voyage then, for the "Arabs" are said to have known of the existence of open sea to the south of that continent. In their first year the mariners landed on Africa, sowed corn, waited until this was harvested and then resumed their voyage. In the second year they again landed and sowed their grain. Thus they took three years altogether for the voyage, returning to Egypt *viâ* the Straits of the Pillars and the Mediterranean.

This report has been much criticized ever since the time of Herodotus, who first recorded it It is curious that the evidences seem much more convincing to us than they did to the old Greek historian, who was thoroughly sceptical about the whole affair. In particular he did not credit the observation said to have been made by the Carthaginians, that, as they rounded Africa, they had the sun on their right hand, though this is just what they should have experienced : at the south of Africa they were in latitudes about 36° S. and so the sun must have been to the north at midday.

Now it is notable that the voyage must have been much more easily made from the east of Africa to the west than *vice versa.* These old vessels sailed with the winds and currents as far as they

were able and they could not stand up into the wind as our modern sailing vessels are able to do. If the fleet left Cape Guardafui (at the southern entrance into the Red Sea) at the beginning of the winter monsoon they would have a favourable wind down the coast of Africa as far as the entrance to the Mozambique Channel.

In the Indian Ocean north from the Equator there are two main, seasonal wind systems—the north-east and south-west monsoons. The monsoons are periodic winds that are set up in the same way as our own familiar land and sea breezes. During the summer months the enormous, highly elevated, Asiatic continental land-mass becomes heated up by the sun so that the atmosphere over it becomes greatly expanded and there is a strong indraught of wind from the ocean to compensate for the upward streaming. Thus from about May there is a strong south-west wind all over the Arabian Sea, blowing in towards the highly heated Asiatic continent. This is the south-west monsoon and it dies away after August. Then, during the winter, the continental land cools down while the ocean remains warm. Air streams up from the water region and therefore winds blow out from the land to take its place. So, from about October to January there are increasing north-easterly winds all over the Arabian Sea and these die away about May.

Therefore the clumsy sailing and rowing vessels of the Phœnicians would have been able to get a favourable wind down the east coast of Africa by leaving the Red Sea at the right time. Further there is a marked drift of water, in the Arabian Sea, during the time of the north-east monsoon, down the African coast from north to south, becoming a strong current, called the Agulhas Stream, which flows down through the Mozambique Channel as far as the Cape of Good Hope. Just as the winds reverse in direction with the season, so also these currents reverse, but, in an intermittent voyage, such as this early Phœnician one is stated to have been, experienced navigators would have taken advantage of the favourable winds and currents. Then on entering the Atlantic Ocean they would also be able to avail themselves of the northerly-flowing Benguela stream which runs up the west coast of Africa from south to north. Here also they would have been favoured by the south-east trade winds. Only the last part of their circumnavigation—from the Gulf of Guinea to the entrance of the Mediterranean—would have been unusually troublesome.

Thus it is probable that the Phœnicians, during their great days,

did actually circumnavigate Africa from the east. It is to be expected, from what has been said above, that the opposite voyage, from the Mediterranean, down the west coast and then round the Cape into the Indian Ocean, must have been much more difficult, and we find no indication in classical literature that it was ever accomplished. That it must have been thought possible is shown by the Map of Herodotus, where Africa is represented as entirely surrounded by water, except in the region of the Isthmus. And there are accounts of actual attempts to make the circumnavigation from the west. Herodotus tells us of such a voyage made by Sataspes, a Persian nobleman who was condemned to death by Xerxes for violating a virgin. He was given the opportunity of sailing round Africa from the Mediterranean in remission of his sentence, and this he attempted but was unsuccessful. On his return he was executed by Xerxes. Then, about 500 B.C., Hanno, a celebrated Carthaginian, is said to have sailed down the west coast with a fleet of sixty vessels, but he only got as far as our modern Sierra Leone (about 6° N. lat.) and then he was compelled to return north. From the time of Herodotus, then, the communication of the Atlantic and Indian Oceans by the south-east was not actually known, but was only doubtfully inferred from traditional report. Then, after the time of Ptolemy the astronomer, the communication was not thought to exist, for all the maps that were based on that of Ptolemy showed the Indian Ocean as a landlocked basin, bounded, to the south, by a great unknown continental land. Not until the time of Henry the Navigator, in the fifteenth century A.D., was the project of African circumnavigation revived.

The Romans in the Indian Ocean. We have seen that, long before the time of the Roman Republic and Empire, there was trade intercourse between the Mediterranean countries and the Far East. Much of this was carried on directly by the Phœnician mariners who themselves made voyages all along the coasts of the Indian Ocean and, in all probability, penetrated the Straits of Malacca and entered Chinese Seas, perhaps even crossing the Pacific. Still it is probable that most of the trade between Eastern Europe and India was carried on by the Arabs. There were markets in the Arabian Peninsula, where commodities brought from India and China by local trading vessels were exchanged with merchants from the west under the supervision of the Arabs. This trade was systematized during the third century B.C.

At that time Egypt was ruled by the Macedonian Ptolemies, who began with the first monarch of that name (Soter, 323 B.C.) and ended with the interesting Queen Cleopatra. Under the first Ptolemy transoceanic Eastern trade was greatly developed. The old canal which connected the eastern branch of the Nile, across the Delta, with the Gulf of Suez was cleaned out and again used. Ports were made in the Red Sea and desert roads were made and controlled. Commodities from the Far East came *viâ* Arabia and the Red Sea to Alexandria, from whence they were redistributed. By the time of Cleopatra, and after the reign of that wanton monarch, this trade had greatly languished.

Then came the foundation of the Empire by Augustus and Egypt became a Roman province. Order was instituted after the turmoil of Cleopatra's adventures. The Nile-Red Sea Canal was again restored to use and frequent expeditions were sent to repress the piratical Arabs of the Red Sea. Trade with India revived, and by the time of Strabo the geographer there were, it was said, 120 vessels engaged in commerce with India and this had become a tolerably safe and regular thing during the great days of the Empire. Still it was for a time a coasting trade. Vessels hugged the land and the ports were, to some extent, in the control of the Arabs. The "fatal limits of the Tigris and Euphrates" interposed between the power of the Empire, to the west, and the trade of the Far East. About the middle of the first century of our era, however, a very important innovation was made. A certain master-mariner called Hippalpus discovered (or rediscovered) the periodic winds, or monsoons, of the Arabian Sea and from his time vessels boldly set out across the Indian Ocean, from the Red Sea, instead of timidly clinging to the land. By sailing at the proper times mariners were able to take advantage of the monsoons, getting favourable winds both going east and returning to the west. It therefore became possible to make a return voyage between the Red Sea and India in the same year, and the importance of this in the first century was very great. More important still was the breaking of the Arab monopoly, or at least their practical control of the Indian Oceanic trade, for the voyage to India was now possible without reliance on the Arab ports. Between the time of Augustus and that of Marcus Aurelius, then, there was a very considerable trade between the Mediterranean, *viâ* Alexandria, and India and China. Various Emperors improved this, for instance Trajan again revived the use of the Nile-Red Sea Canal

(" Trajan's River "). Marcus Aurelius even sent embassies to China and there grew up a mutual appreciation of the honesty of both the Roman and the Chinese merchants. One is impressed with the " modernity " of the transoceanic commerce of the Roman Empire.

With the decadence of the third and fourth centuries this trade languished and practically ceased. Then, when Byzantium became the centre of the civilized world, trade with China went mostly overland, much in the same way as Marco Polo travelled in the thirteenth century. The sea route had to be redeveloped and this, as we have seen, was left for Portugal, after the Dark Ages had passed, and when geographical enterprise had again been revived. We have dealt with all this in Chapter III.

The Physical History of the Indian Ocean. Now look at Fig. 41, which is a chart of the Indian Ocean showing the depths (the contour lines have been drawn directly from the Admiralty charts). In all such representations of ocean depths there is great difficulty and always some uncertainty because the available soundings are far too few for the purpose. Nevertheless the chart enables us to make some general observations which will help the student.

The Indian Ocean is, on the whole, less interesting than are the Atlantic and Pacific regions, and we have only to note that it presents many of the general physical characters exhibited by the other two basins.

In general it is shallower and there are none of the great deeps that we find in the Pacific. The deepest parts are those situated to the south of Sumatra, and here there are soundings of over 3,000 fathoms. On the western side there are also marginal deeps which are mostly between 2,700 and 3,000 fathoms: these we see to be situated to the south and east of Madagascar and just off the coast of Somaliland. Thus there are relatively deep regions on the eastern and western margins and there are also indications of marginal depressions in the northern part of the Arabian Sea and south of the Indian Peninsula.

Centrally (but not at all symmetrically) the Indian Ocean is shallow. There is a shoal area that (curiously like the Central Atlantic Rise) runs down the central part of the Indian Ocean from India towards Madagascar and where the depth varies from 1,000 to 2,000 fathoms. On this Central Rise there are large areas of water which are less than 1,000 fathoms in depth, and here we find the Indian Oceanic Islands.

The Indian Oceanic Islands. These are the Chagos, Seychelle, Maldive and Laccadive groups. Thus we see, as in the Pacific, a series of oceanic archipelagoes surrounded by deep water. Here also we find coral formations, though the typical groups of atolls are not nearly so well displayed as they are in the Pacific Ocean and the mode

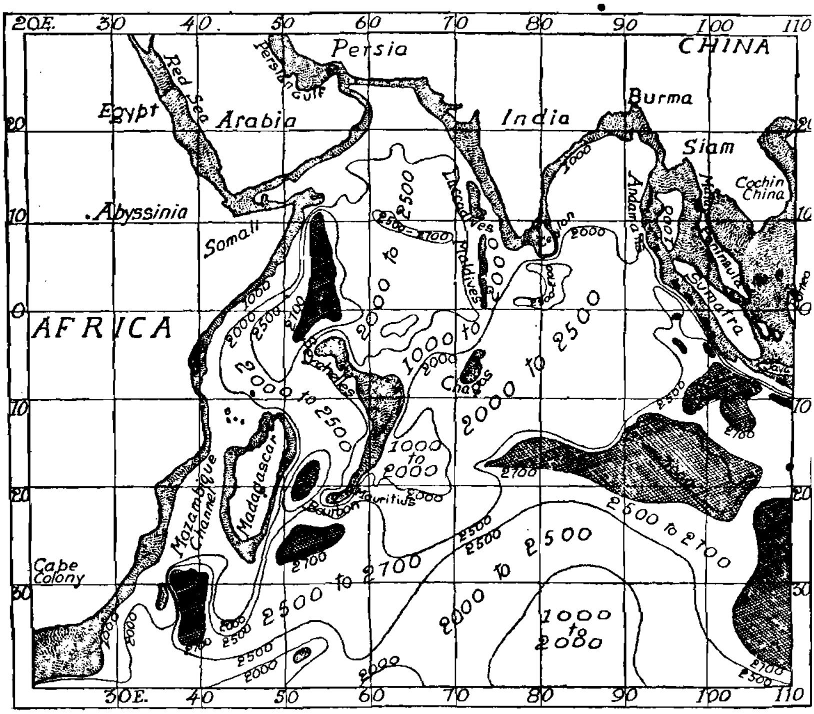


FIG. 41.—Sketch Chart of the Indian Ocean.

The region of continental shelf is stippled. Cross-hatching represents the deeps (over 2,700 fathoms in this case). Depths of over 3,000 fathoms are outlined heavily.

of formation of the Indian Ocean coral reefs probably differs in many ways from those which we have already studied. The occurrence of these island groups situated on central shoal regions is interesting.

The Tributary Seas of the Indian Ocean. These are the Red Sea, the Persian Gulf, and a region lying just to the west of the Malay Peninsula which we may call the Andaman Sea. The Arabian Sea and the Bay of Bengal are merely great gulfs of the Indian Ocean

fringed with extensive marginal zones of water which is between 1,000 and 2,000 fathoms in depth and having extensive regions of continental shelf.

The Red Sea is a "Rift Valley." That is, it has been formed by two series of fault-zones, one situated along each margin. Here the sedimentary rocks have been fractured and the whole region between the opposite coasts has dropped down, so to speak. The whole of the Red Sea bottom is continental shelf and the depth of water is, in general, less than 1,000 fathoms. On either side of the Red Sea, but particularly on the western margins, are extensive regions of coral reef. This sea is the only one on the earth that has the structure of a rift valley.

The Persian Gulf is merely a drowned river valley of extensive dimensions. It, too, is shallow, being situated entirely on the continental shelf.

The Andaman Sea is an epicontinental basin. Along the Burmese coast and towards the mouths of the Irawadi runs a range of mountains, the Arakan Hills. This earth-fold is continued to the south as a submarine elevation, of which the Andaman Islands are the highest parts. Turning toward the east this elevation is prolonged by the arc of islands beginning with Sumatra. Thus the Andamans form the visible parts of an insular arc the convexity of which faces west and which encloses an epicontinental sea. The latter is mostly very shallow, containing large regions of shelf bottom, but there is also an extensive area where the depth is over 1,000 fathoms and a small region where there are depths of over 2,000 fathoms. The Andaman Sea is the only instance of an epicontinental region in the Indian Ocean.

The Oceans Compared

Thus we see the same general plan in all three oceans. Centrally, or roughly so, there are regions of relatively shallow water:

The Central Rise in the Atlantic;

The region of South Sea Islands in the Pacific;

The Chagos-Seychelles-Maldive shoal in the Indian Ocean.

Marginally there are the deeps.

In all three oceans also there are the indications of depression. There was always an Equatorial-Atlantic Ocean—the Sea of Tethys

(Figs. 42 and 43)—and sometime in the Mesozoic Period (see page 16), the continental lands to the north and south of this (North and

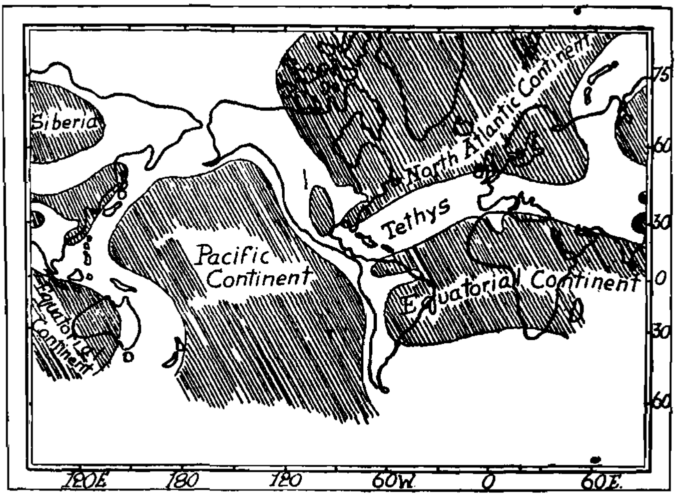


FIG. 42.—The Oceans in Devonian Times. The figure is based on Haug's Reconstructions of the past distribution of Land and Ocean.

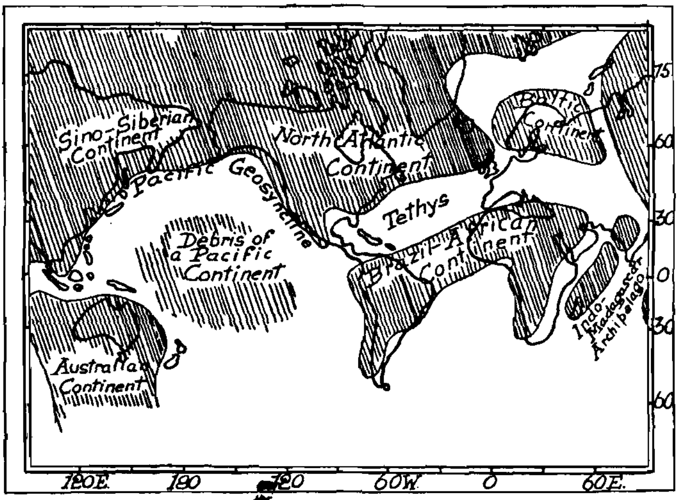


FIG. 43.—The Oceans in Tertiary Times. Based on Haug's Reconstructions.

South Atlantis) foundered with the formation of the North and South Atlantic basins. There had been for a long time (probably back into the Paleozoic Period) a great circum-Pacific geosyncline ;

probably a series of seas fringing what are now the Pacific coastal lands. Sometime in the Tertiary Period the extensive region of land and shallow seas that occupied the site of the present ocean also foundered and the last traces of this ancient Pacific Continent are the relatively shallow regions marked by the Polynesian Archipelagoes. Lastly there appears to have been an Australo-Indian Continental region extending across between Africa and Australia, and sometime between the Cretaceous and Eocene Periods this also foundered, leaving as its last traces the central Indian Oceanic Archipelagoes.

Thus most of the evidences of great changes in the past distribution of sea and land point to one interesting result—that throughout geological time there has been a gradual increase in the volume of the ocean. Great regions of land have apparently undergone depression, while there are no indications that extensive regions of deep ocean bottom have ever undergone upheaval. Probably what has happened has been the gradual rise in ocean level (that is, the gradual increase in its volume), thus drowning the lower, less stable continental lands. With this has proceeded the process of warping of the ocean beds (see p. 23), so that most of the deeper regions of ocean bottom are situated near to the continental margins.

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SUGGESTIONS FOR FURTHER READING.

VOYAGES, ETC.

"History of Classical Geography," Bunbury (John Murray).

The Series, "Great Explorers" (Philips).

[But there are numerous books on the great voyages of exploration, and the reader will easily trace these in any good library catalogue.]

POLAR EXPLORATION.

"Siege of the South Pole," H. R. Mill.

"Polar Exploration," W. S. Bruce (Williams & Norgate).

"The Polar Regions," Rudmose Brown (Methuen).

"The Voyage of the *Discovery*"; "Scott's Last Expedition" (John Murray).

[The most humanly-moving and impressive of books on polar exploration. Their reading must not be omitted.]

OCEANOGRAPHY.

"The Ocean." John Murray (Williams & Norgate).

"The Realm of Nature," H. R. Mill (John Murray).

"Founders of Oceanography," W. A. Herdman, (E. Arnold).

"Introduction to Oceanography," J. Johnstone (Liverpool University Press).

MARINE BIOLOGY.

"Conditions of Life in the Sea," J. Johnstone (Cambridge University Press).

[The above are all simple books and easily read. See other references in the appendices.]

APPENDICES

The *following titles* refer to amplifications of various matters treated in Chapters I, III and IV. Some references to the sources of information are given.

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Wegener's Hypothesis of continental displacements . . . 212

(See further, "Surface features of the Earth," Joly, also "The Earth," H. Jeffreys, Cambridge University Press).

CHAPTER III.

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("Navigation," W. Hall, Jack; The "Admiralty Manual of Navigation"; "The Marine Chronometer," Gould, Potter; "The Arctic Regions," Sir John Barrow, 1818).

CHAPTER IV.

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Climate and the Ocean 222

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(Article on "Tides" in supplementary vol., Ed. XI, Encyclopædia Brit.; article on "Tides," in "Merseyside," Handbook to the Liverpool meeting of the British Association; References to literature on oceanography and climate in Johnstone's "Oceanography"; see also Jeffreys, "The Earth").

APPENDIX TO CHAPTER I.

Isostasy.

Let g (the acceleration due to gravity) be taken as a convenient measure of the earth's gravitational force. This coefficient can be found by observing the acceleration of a falling body. Now the shape and density of the earth are irregular, and so g varies from place to place. It is greater at the Poles than it is on the Equator because a Pole is 13 miles nearer to the centre of the earth than is a point on the Equator. It is also greater near mountains (*that are not too big*) because these are local excesses of mass. It is also greater where the earth's density is locally more than the average density, because there also is an excess of mass.

The estimation of g. A body that falls freely is accelerated, and by observing the acceleration g can be calculated. A pendulum bob is substituted for the imaginary falling body, because the bob really falls once in every swing, from its highest to its lowest position. If the bob is accelerated in fall it follows that the pendulum will oscillate more rapidly (because the time of fall from highest to lowest positions will be decreased). Therefore by counting the number of swings of the standard pendulum in a given time we can accurately measure the coefficient g.

The Schiehallion Experiment. It was found long ago that the mountain Schiehallion exercised, by its local excess of mass, an attraction on he plumb-line, pulling the latter out from the true vertical. (It would also have increased the rate of oscillation of a pendulum). Much later it was found that the local attraction of the Himalayas was far less than it ought to have been, on the hypothesis that these mountains represented a local excess of mass. This contradiction has been explained by the theory of isostasy.

The Attraction of an Iceberg. A large iceberg floating in the sea appears to represent a local excess of mass—all that solid water projecting above the surface. But it exercises no attraction at all on a plumb-line or an oscillating pendulum near it—no matter how delicate the apparatus, and how accurate the observations. The reason is that the density of the berg is about 0·92, while that of the sea water is about 1·0025. The part of the iceberg below the surface displaces heavy sea water by light ice, and so the berg floats. There is an excess of mass above the

surface, but there is a compensatory defect of mass below the surface. Therefore the iceberg exercises no local attraction.

Isostatic Compensation. Just so with the Himalayas. They behave, with regard to the pendulum, as if they were a thin shell of rock with nothing inside. Actually their density is about 2·7, while that of the earth crust below the ocean floor and for about 30 kilometres down is about 3·0. The rocks of the Himalayas (density about 2·7) are embedded in a basaltic substratum (density about 3) and they displace the latter, or rather replace it (some 25 to 30 kilometres down) by lighter rock. The case is entirely analogous to that of the iceberg. In the Himalayan region there is an excess of mass (light continental rock) above the mean geoidal level but there is also a defect of mass (a defect of heavy substratal rock) below the geoidal level, and defect and excess just compensate each other.

This is because *great* earth-features, like the Tibetan Plateau, press down into the substratum of heavy basaltic rock and displace the latter, just as the iceberg displaces denser sea water.

But *small* earth-features, such as Schiehallion, are supported by the rigidity of the underlying continental rock—a degree of rigidity which would not support the Tibetan Plateau.

This is isostatic balance. If the Tibetan Plateau were to be covered by a thick icecap (like that of Greenland) it would be pressed down into the substratum still further, and there would be no increase of local attraction because more dense rock beneath would be pushed away. Conversely, if the Plateau were to be eroded away the roots in the dense rock would be pushed up (just as when the visible part of an iceberg melts and sea water displaces ice beneath the surface). So although excess of mass above geoidal level would be removed, there would be an addition of mass below the geoidal level due to the dense substratal rock that has flowed in, and again there would be no local attraction.

Wegener's Hypothesis of Continental Displacements.

This can be modelled by cutting out paper shapes (with curvature) of the continents, and attaching these to a globe, with wet paste, or slowly-drying gum. Then the shapes can be pushed about on the surface of the globe and made to fit into each other—it is quite interesting. To make the hypothesis plausible it has to be shown (1) that longitudes of places may change and (2) that there is some competent force which will account for the displacements imagined in the hypothesis.

The latter supposes that the Western ocean border of Eur-Africa once fitted into the Eastern borders of N. and S. America; that Greenland fitted into a wedge-like cavity left on the North; that as the Americas drifted apart from Europe and Africa the motion caused the Andes, etc., to ruffle up; that the continents really float on a substratum of denser rock, and can be moved

through the latter; that this denser, yielding substratum is represented in the ocean beds, and so on.

Shearing Stresses. If, when the paper shapes are pasted on the globe, they are pushed horizontally they will slide on the wet paste. The materials, globe—paste—paper, are continuous and they are said to *shear* in the region of the paste. This material has minimal strength, and so a very small horizontal shearing-stress, exerted for a long time, will set up a very large displacement (the continental paper-shape can be moved all over the globe). It is supposed that very small forces, acting for long periods, have caused the continents to move on a shearing layer in the earth's crust. Such small forces are the horizontal tidal ones, precessional forces, and differences of gravity between the tops and bases of mountains. The horizontal tidal force in the case of a mountain is about one ten-millionth of the weight of the latter.

Now about 700 to 1,000 kilometres below the surface of the earth there is probably a layer of rock of zero strength, or nearly so. A very small force continually applied in one way would cause the upper earth-crust to shear on the kernel—but the upper crust would move as a whole *and there would be no displacement of the continents relatively to the oceans.* It is probable that such deep shearing movements do occur.

Inadequacy of the forces for displacements of the Continents. If, in our model, we imagine the paste to become dry and hard, then the small horizontal forces will no longer shear the shapes on the surface of the globe—the pasty material will have become *strong.* Now the materials of the bases of the continents and of the oceans beds and of the layers of the crust immediately beneath are strong and so no forces of the kind envisaged in the hypothesis, *no matter how long they may be exerted,* are adequate to shear the earth crust as required. And such an effect as the upraising of the Andes by the advancing W. American continental coasts can be approximately evaluated while the forces at our disposal are entirely inadequate for that effect.

No observed longitudinal changes. Very small recurrent and non-cumulative changes of latitude (down to 0″·01) have been observed, but there is no conclusive demonstration of analogous changes of longitude.

Therefore, Wegener's hypothesis is probably erroneous.

(See further, "The Earth" H. Jeffrey, Cambridge University Press, 1929).

APPENDIX TO CHAPTER II.

Methods of Navigation.

Most of the great exploratory voyages were made in small ships, with small crews and with most crude navigational methods. Fishermen at the present day have to pass Board of Trade examinations. They may take small vessels to the Barents Sea, Iceland, Davis Straits, the coast of Morocco, but they cannot be said to navigate [" He was two days finding Iceland after he had run his distance."] It was in this way (barring that they had a clumsy way of finding approximate latitudes) that Robert Bylot, with William Baffin as pilot made, in 1616, the most notable of Arctic voyages. The ship was a barque of 55 tons, and the crew were 14 men and a boy.

The Mariner's Compass. The instrument was used from " time immemorial." The lodestone originally floated. By and by it was replaced by the magnetised steel needle. About the end of the thirteenth century the needle was poised on a pivot and the well known compass card took its form. The Fleur-de-lys marking the N-seeking end, is said to have been devised by Flario Gioia Amalfi in honour of the Neopolitan Sovereign, whose family was allied to that of France. The modern, accurate mariner's compass has two main forms, (1) the needles swing in 50% alcohol in a closed bowl, and (2) the lightly magnetised needles carry a very light card. These instruments and the gyroscopic compass are products of the late nineteenth century.

The Sounding Lead. The forms still used by fishermen ("hand-line " and " deep sea line ") are of ancient date. The modern sounding machine is due to Sir William Thomson, who used pianoforte wire as the " line." The " Challenger," with true Admiralty conservatism did not use steel wires, or ropes, and her sounding was done with a ½-inch rope.

The deep sea sounding machine carries about 6,000 fathoms of pianoforte wire (smaller depths are sounded with a strand of seven wires). The sinker that replaced the old " lead " is slipped automatically before the wire is wound inboard (or a cable-laying ship may simply cut the wire and leave it on the ocean floor (time being more valuable). Sounding on trading vessels, ships of war, etc., is usually done by the " depth recorder "—which has a narrow glass tube, sealed at one end, enclosed in a metal tube not far from the sinker. The inside of the glass tube is coated with silver chromate (red) and this is bleached by contact with sea water. The tube when let down has air in it, and this

is compressed (according to Boyle's law) by the pressure of the water. The line runs out at an angle—the ship steaming all the while, and the machine signals when the sinker strikes bottom. When the wire is brought in the glass tube is detached and laid against a scale which indicates the depth, according to the height to which the water has been forced up the tube.

In men-of-war empirical methods may be used. The speed of the vessel has been related with the angle at which the wire, carrying the sinker, descends. Tables give the depths, from this angle and the length of wire run out when the bottom is touched. (These two methods avoid stopping the ship when a sounding is to be made).

Accurate depths are obtained only when the ship is stopped, when the line is straight up and down, and when machines precisely signalling the striking of the bottom are used.

Acoustic soundings can be made almost continuously when the ship is under way. A small explosion, just outside the bottom of the ship, is made and accurately recorded, and so is the receipt of the echo from the bottom. Corrections must be made for varying salinity and temperature (which affect the velocity of sound waves in water). A somewhat similar method makes use of radio (electromagnetic) waves.

In precise oceanographic investigation the modern sounding machine and the pianoforte wire are always used.

The Sextant and Latitude. Newton is said to have devised (but not made) what is practically the modern sextant—this was in 1700. R. Hadley first made the instrument, about 1731. It was really an octant but, later on, the arc was increased to $\frac{1}{6}$th, and even $\frac{1}{4}$th of a circle.

The modern instrument is very perfect. Its main use is to find the altitude of the sun when he crosses the meridian—the observation is to find (1) the greatest angle between the lower limb of the sun and the horizon: at (2) the moment when the sun is highest in the heavens it is noon (at the ship). But such angles as those between the moon and certain fixed stars; between the top of the lantern of a lighthouse and the sea level; between two well-defined objects on the land; between two lights on a ship ahead, and so on, can also be found by the sextant.

Longitude and the Chronometer. To find the longitude at sea was originally a great problem: before the invention of the chronometer seamen depended on dead reckoning. There were astronomical methods, which were impracticable in the early eighteenth century. Galileo showed how longitude could be found by observations of the occultations of Jupiter's satellites, and it was also known that it could be found, in theory, by observations of the moon's place among the fixed stars.

These methods depended on finding the local time, and also the time referred to the prime meridian. The latter time would

be given by an accurate clock, keeping the standard time, and carried on the ship, but no such clocks were known prior to the period of John Harrison. The moon, in her passage among the stars, was known to be at certain angular distances from certain stars at definite times referred to the prime meridian. If these places of the moon could be tabulated, with their respective times, then the standard time could be found at sea by lunar observations.

The office of Astronomer-Royal was founded by Charles II, who appointed John Flamsteed. The duties were to draw up "Tables of the Heavens and the places of the fixed stars, in order to find out the much-desired longitude at sea for the perfecting of the art of navigation." Flamsteed began to make the tables, and latterly these became the Nautical Almanac.

In 1713 the British Government offered rewards of £10,000 £15,000 and £20,000 respectively for the discovery of the means of finding the longitude at sea with an accuracy of 60, 40 and 30 minutes. A committee was appointed and latterly this became the Board of Longitude (which was dissolved in 1828) and had to do with the granting of the rewards. It must have seemed as if the problem at issue were an insoluble one. Swift (writing in 1726) makes Gulliver visit Laputa and see the Struldbrugs—whose opportunities he envied. If he were to be immortal, he says, he might "then see the discovery of the longitude, the perpetual motion, the universal medicine, and many other great inventions brought to the utmost perfection."

John Harrison came to London in 1728, and by 1735 he had made his first chronometer. This was tried at sea with satisfactory results, and Harrison received £500 from the Board of Longitude. He made other chronometers and in 1749 the Royal Society awarded him its Copley Medal and would have made him a Fellow had he wished this. Harrison's fourth chronometer was duplicated and used by Capt. James Cook. Thus we may say that by 1749 the invention of an adequate chronometer had been made and recognised. In 1757 Harrison asked that the Admiralty allow his timepiece to be tried on one of H.M. ships, and, impressed with the great urgency of the problem, that body allowed the trial—in 1761. The tests were successfully passed. There was another trial in 1764, and Harrison claimed the reward. Maskelyne, the Astronomer-Royal, had to adjudicate and he would have divided the reward between Harrison and Johann Mayer, who had made lunar tables, and submitted these to the British Government

In the end Harrison got the £20,000 (or the balance of it), but only in 1773 and after the personal intervention of George II. Mayer's widow got a reward of £3,000 from the Government.

The chronometer has, of course, been improved since Harrison's time, but it is not now the indispensable instrument it was.

Since the war standard time can easily be found at sea with an accuracy of 1/100th second, from wireless signals. Much less business is now done in rating chronometers: presently ships will use clocks automatically regulated by relays worked by wireless impulses.

(See further, " The Marine Chronometer," R. T. Gould, Potter, London, 1921).

The Franklin Record.

There were really two messages from the lost expedition that were subsequently found by Capt. McClintock, steam yacht "*Fox*," sent by Lady Franklin, in search of traces of the missing explorers, in 1857-9. The earlier record, signed by Lieut. G. Gore, 1st Lieut., and C. F. des Voeux, both of the "*Erebus*," reported all well. On the same paper was another record, written later and signed by Captain Fitzjames of the "*Erebus*" and by Capt. Crozier. This stated that Franklin was dead and the ships had been abandoned.

Amundsen at the North Pole.

Amundsen made an attempt to fly from Spitzbergen to the Pole in May, 1925, with two areoplanes. The voyagers were forced to descend at a distance of 177 miles from their objective. His party remained on the ice for 24 days. Then they cleared one plane and flew back to Spitzbergen. In 1926 Amundsen made his second successful attempt, crossing the Pole on 12th May, and then flying on to Cape Barrow, in Alaska. The means employed was the airship " Norge," which was brought from Italy with Capt. Nobile, its constructor.

The loss of Amundsen, in 1928, in an attempt to rescue Nobile's party after their disaster is within memory of the reader.

The Ships " Discovery."

The curious way in which the names of English ships are perpetuated is illustrated by the case "*Discovery*." No less than nine vessels, all employed in the work of exploration are on record. These ships appear to have made 14 voyages of investigation up to the present time. (But all the sources of information have not been consulted.) The list is as follows :—

I. *Discovery* (Flyboat, 70), *Capt. George Weymouth*, 1602.

Sent by the Muscovy Company. This was the first great English Joint-Stock Corporation for foreign trade. It was incorporated in 1555, with Sebastian Cabot as Life-Governor. It was re-incorporated in 1576-7. It sent the *Discovery* to the coasts of Labrador apparently for the purpose of whaling, for which industry it had received a monopoly under its second charter.

II. *Discovery* (Barke, 55), *Henry Hudson*, Master, 1610.

(*a*) This was Hudson's fourth voyage to Hudson Strait and Bay. There was a mutiny and the Master lost his life. The ship came home safely.

(*b*) *Captain Ingram*, with the *Resolution*, *Captain* (afterwards *Sir*) *Thomas Button* in command, 1612. Prickett and Bylot, two of Hudson's mutineers, were on in this expedition, which went to, and crossed Hudson Bay.

(*c*) *Captain Gibbons*, 1614. There was a Company for the Discovery of the North-West Passage. (Sir Thomas Smith, Sir Dudley Digges, John Wolstenholme and others.) These men sent out the expeditions of 1610, 1612 and 1614. Gibbons appears to have reached the coast of Labrador and wintered in a bay called "Gibbons his Hole" (Nain).

(*d*) *Robert Bylot*, Master, and *William Baffin*, Pilot, 1615. The Company of merchant adventurers referred to above sent out two more expeditions. The present (with 14 men and a boy) went to Hudson Bay.

(*e*) *Robert Bylot*, Master, and *William Baffin*, Pilot, 1616, (and 14 men and a boy). This was probably the most important Arctic Expedition ever made. It found Baffin Bay, Lancaster Sound, Smith Sound, etc., thus the approaches to the Polar Basins and the N.W. passage.

III. *Discovery* (Sloop), *Captain David Vaughan*, with the ship *Albany*, Capt. Geo. Barlow, 1719. *James Knight* (who was in command of this expedition) was an officer of the Hudson Bay Company. The Company was bound by its charter to make explorations, but it was always reluctant to do so. This was such a voyage. The ships were lost, with all hands, and a relief vessel found no traces of the *Albany* and *Discovery*.

IV. *Discovery* (Pink), William Moor, Master, 1741, with the *Furnace* (Bomb), Capt. Christopher Middleton. There was a Mr. Arthur Dobbs who tried to induce the Hudson Bay Company to search for a passage into the Pacific. Finally he persuaded the Admiralty to send an expedition in command of Capt. Middleton, who had been an officer of the Company. The ships went to Hudson Bay.

V. *Discovery* (a converted collier, about 300). Captain Charles Clerke, 1776-9, with the *Resolution* on Capt. James Cook's third voyage in the Pacific and Arctic oceans.

VI. *Discovery* (Sloop-of-War, 300). Capt. George Vancouver, 1790-95. Vancouver was with James Cook on his second and third voyages. In the above voyage he circumnavigated Vancouver's Island.

VII. *Discovery* (a Steamer, 600), Capt. Stephenson, 1875-60, with the *Alert*, Capt. George Nares, in a voyage to the N. Polar Sea, via Smith's Sound.

VIII. *Royal Research Ship, Discovery* (Barque, with steam, 485), Lieut. Robert Falcon Scott, 1901-4. The first ship specially built for exploration in Great Britain.

(*a*) Scott's first voyage to the Antarctic Continent.

(*b*) With Capt. Stenhouse and Dr. S. Kemp (in charge of the scientific work), 1925-7. Associated later with the whaler

Wm. Scoresby. This was an investigation into the whaling in Antarctic seas, carried out at the instance of the Government of the Falkland Islands.

IX. *Royal Research Ship, Discovery II* (Steamer, specially designed for oceanographical investigation), Commander W. M. Carey, R.N. and Dr. S. Kemp, Scientific Leader. Expedition to the Antarctic in continuation of the work of *R.R.S. Discovery,* 1925-27. 1929.

Sir John Ross, in 1829, called his ship *Victory* (the first steamship to engage in exploration) the *Discovery Ship Victory.*

It has been said that the *Discoveries* have been fortunate vessels, and that has generally been the case. But Henry Hudson lost his life in a mutiny on board the second *Discovery* and the third *Discovery,* with Capt. D. Vaughan, was lost with all hands.

(See further, "Voyages into the Arctic Regions," John Barrow, London, 1818).

APPENDIX TO CHAPTER IV.

THE TIDES.

The well-known text-book diagrams show how the attraction of the moon throws the water of the ocean into a figure of equilibrium. There are two low elevations of sea level on the ocean 180° of longitude apart. We may think of the earth-body as slipping round underneath these elevations, so that two tidal undulations pass any place on a meridian of longitude every lunar day.

Now it is only in a strip of the Southern Ocean some 600 miles or so wide (between Cape Horn and Graham Land in Antarctica) that there is an uninterrupted ocean. The Pacific, Atlantic and Indian Oceans may be regarded as great "gulfs" opening out from the Southern Ocean. The tidal undulation originating in the latter has been said to be deflected into the gulfs, thus travelling to the N. So the tidal undulation that traverses the North Atlantic has been said to be the same undulation that was in the Southern Ocean a day or so previously.

But the attraction of the moon and sun establishes oscillatory elevations in, say, the N. Atlantic independently of those in the Southern Ocean. It is true that the latter oscillations affect sea level in the N. Atlantic, nevertheless the characteristics of the tides in the latter region depend on its dimensions, forms, depths, etc. In the same way lunar and solar attractions throw the water of, say, the North Sea, into oscillations independent of, and very much smaller than the oscillations in the N. Atlantic. The tides in the North Sea are therefore largely dependent on those in the Atlantic, but their characteristics depend on the dimensions, form, depth, etc., of the N. Sea. So also with the tides of other tributary seas.

Further than these bald statements we may not go without resort to much hydrodynamical theory—and its consequent mathematical formulation. The reader who feels competent to enter on such a study should begin by reading J. Proudman's article, "Tides," in the *Encyclopedia Britannica.* (He had better consult the 14th edition, second printing, as some copies of the first printing contain defective versions of the author's article.)

Tidal Predictions. First, the actual rise and fall of sea level must be recorded, for several years, at some place by means of a tidal gauge. These data are then submitted to *harmonic analysis.*

The *whole* tide is due, in the first place, to sun and moon, but the attractions of each of these bodies contributes to the whole tide. Then, the visible motions of each heavenly body can be decomposed into several motions, all strictly periodic and accurately predictable from astronomical theory. Thus the moon has a motion of declination (from Equator to above and below Equator) with a fortnightly period; the sun has an analogous motion of declination with a six-monthly period; the moon moves from apogee to perigee in a fortnight, and the sun moves from aphelion to perihelion in half a year; and so on. There are twenty to thirty such motions and each of them modifies the total attraction that sets up the tidal oscillations. There are also other contributory tidal causes that are not strictly associable with astronomical events.

Each separable motion can be regarded as setting up a separable "partial" tide.

Harmonic Analyses. Knowing, a priori the periods and phase-relationships of these partial causes, and knowing the total tides at some one place it is possible, by a kind of "averaging," to cancel out all the partial tides except one. This is done for every partial in succession. The mathematical artifices developed are of extraordinary elegance and ingenuity. So for each partial we can make an equation of the form:

$$\text{Height of the tide} = a \sin (bt + c).$$

where a gives us the *amplitude* of the undulation; b gives the *period* and c is the phase of the undulation at zero time. Time is t.

Thus, for any place where tidal observations have been made we can construct some 20 to 30 equations like the above. From these we can predict the tides at that place, "for ever." [It is true that there are partials of $4\frac{1}{2}$, 8, etc., up to about 1,600 years in period, but these can be neglected in purely utitilarian predictions].

Harmonic Syntheses of the Partial Tides. The obvious, straightforward and perfectly impracticable way of predicting the tides for any one place is to find the equations of all the partials, and then solve them for values of t given by every hour, every day, throughout the year. The 20 to 30 values for each equation and each hour are then added algebraically and the result is the total tide. But in practice all this is done by a machine, the development of which, from the time of Lord Kelvin up to the present represents real human genius. The principle of the machine is easily understood.

There is a component wheel for each partial and the velocities of rotation of these wheels are proportional to the periods of the partials;

The lengths of the cranks are set so as to be proportional to the amplitudes of the partials;

The positions (angular) of the cranks are set so as to represent the phases of the partials;

As each wheel rotates the crank and connecting rod communicate harmonic up and down motions to the pullies ;

The tape is kept tight in grooves in the peripheries of the pullies and all the harmonic motions (up and down) of the latter

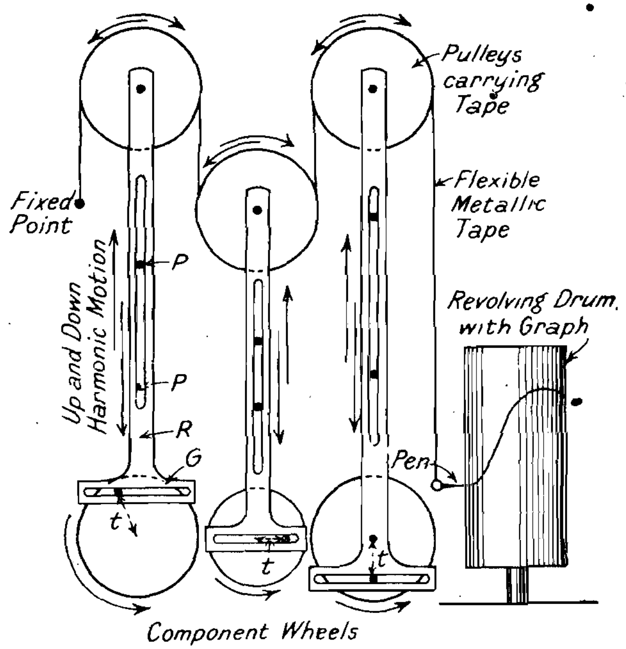

Fig. 44.—*Explanation of figure.* The rods *R* move vertically up and down. The pins *P*, working in the vertical slots, give this vertical motion. The cranks (not shown) have pins that can be set at variable distances from the centres of the component wheels. These pins work in the horizontal slots on the pieces, *G*, of the rods, and as they revolve cause the whole rods *R* to move up and down.

integrate so as to give a harmonic (up and down) motion to the pen ;

The pen writes a resultant graph of all the partial harmonic motions on the roll of paper.

This graph is to scale. Its ordinates (on time abscissae) are measured, and so the data of the tide-tables are obtained.

" Climate " and the Oceans.

By " Climate " is meant here :—

(1) Big changes involving large regions and long periods of time (example—the European, Tertiary Ice-age).

(2) Small changes involving smaller regions and time-periods

(example—the relative freedom from ice of the S. and E. coasts of Greenland in medieval times).

(3) Differences between regions on the earth that are not far apart (examples—Labrador and Britain, Scotland and Moscow).

(4) Small differences from average condition between year and year (example—the times in the years that some Baltic ports freeze up).

All these, as well as " weather," have much to do with the ocean.

(1) *The big changes.*

" Ice-ages " involve large regions and tens, or hundreds of thousands of years, or so, of time. They have been associated with variations of solar radiation and with the varying " exposures " of terrestrial regions to solar radiation associated with the precessional " postures " of the earth. These hypotheses have not been sustained.

On the other hand their association with (*a*) relative elevations of *continental land*, (*b*) *variable distribution of land and sea*, and (*c*) variable directions and intensities of oceanic drifts tends to become more probable. The effects involved in ice-ages, etc., *are geodetically very small ones*, and not much has to be explained quantitatively. It is to be noted that these great climatic phases do not occur with regularity. The primary causes are to be found in the great earth crustal movements that happened in the " earth-revolution " crises.

(*a*) Differences due to continental elevation are easily seen—the temperature of the Tibetan Plateau and that of E. China; the influence of elevated Asia in maintaining the system of monsoons, etc.

(*b*) Variation of land and sea—the continental and insular climates (Moscow and Edinburgh). Sea water, from its high specific heat tends to vary in temperature far less than continental land. Also the Antarctic continent.

(*c*) Ocean drifts and currents carry heat (the "Gulf Stream,") or remove heat (the " Labrador Stream "). This is an important factor. N.W. Europe receives heat from the N. Atlantic drift, which the earth's rotation deflects to the East.

Ocean drifts occurs slowly (say a mile or less per day) but the quantities of heat carried are enormous. The drifts occur in wide and *deep* seas, and are much impeded by limited depths. Thus the N. Atlantic drift is greatly impeded by the region of shallow water extending from Greenland to Scotland. The N. Polar Ocean thus receives far less heat than it would do if the " barriers " or shoals, between Greenland and Scotland, and between N. Greenland, Spitzbergen, Franz Joseph Land and Siberia were removed—by deepening of the seas in those regions. On the other hand, complete drying up of the sea in those limited

regions would practically isolate the N. Polar Ocean, so far as effective heat exchange with the Atlantic matters.

Such barriers to oceanic drifts have frequently been formed—and removed—in geological time. (But note that a *deep* ocean is not known to have become continental land.)

The series of explanations is probably good enough to account for the ice-ages, temperate and tropical conditions in high latitudes, etc. Nevertheless, evaluation of the heat conveyed and removed must be made to establish the explanations. As yet oceanographical data do not permit such evaluations.

Also these considerations explain the effects under (3) Labrador bathed by a cold stream and England and Ireland bathed by a warm stream. Heat is conveyed.

(2) *Moderately big changes.*

Local changes of climate extending over considerable, or short periods (as measured in hundreds or thousands of years, say) can be variously explained.

The transgressions of the sea over the low-lying land, or the retreat of the sea from the continental shelf regions will produce climatic changes. The latter may be long in duration (but it is difficult to make estimates). The transgressions are local—N. America, West Europe, etc, and mainly occur in the phases of diastrophism (in the revolutions).

(3) *Tidal Effects*—ice round Greenland—formation of Zuyder Zee, Icelandic vulcanism, etc. There is a constellation of positions of the sun, moon and earth, in which the tide-generating force is at an absolute maximum :

The line of the earth's apsides, the line of the moon's apsides, and the line of the moon's nodes all coincide; the earth is in perihelion and the moon is in perigee. When, at this time, there are spring tides and the sun and moon are in positions of minimal declination the tides will be great. The ranges, velocities of tidal streams and amplitudes will be maximal. Such great tides (especially when "surges" occur—as in the cases of London flooding in recent years) will lead to erosions and other local topographic effects. This is believed to be the cause of the relative freedom from ice of Greenland seas at one time; of the frequent freezings of the Baltic in the 13th to 15th centuries; of frequent volcanic eruptions and earthquakes in Iceland between 1200 and about 1350.

(4) *Small Changes from year to year.*

There are differences from year to year in the durations, amplitudes and phases of, say, the N. Atlantic stream, where it bathes N. Europe. Many local effects are due to these changes. But here again the said changes have not been adequately evaluated.

References (see the author's text-book on oceanography, where there is a short bibliography.)

Life in the Ocean.

There is life everywhere in the ocean and its tributary seas (except in a few very local places where entire stagnancy of the water is the case, in the deeps.) No extremes of temperature of the ocean, of pressure, and of light or darkness entirely inhibit life of some kind. Plant life may even be present in frozen sea-water.

Animal and plant life. Animal life is present everywhere except in the local, stagnant, deeps referred to above and in sea-ice. Plant life is present everywhere where is enough light—that is, generally in all levels of the sea above about 200 fathoms.

The Categories of Distribution of Life. Plants and animals that live on the foreshore, or on the sea-bottom as rooted, sessile, semi-sedentary and burrowing organisms are the ***Benthos***. Examples are seaweeds, zoophytes, sea-anemones, corals, etc. Animals that are large and actively locomotory are the *Nekton*, and examples are fishes, whales, cuttlefishes, etc.

Organisms that are usually microscopic and simply drift about in the ocean and seas are the ***Plankton***.

Neritic and Oceanic Organisms. The proximity of the land (fresh water, organic debris, colloidal clay, sands, muds, variations of temperature, etc.) influences the forms of life. Such species as live near the land are *Neritic* and those that inhabit open seas and oceans are *Oceanic*.

The Zonal Distribution of Life. Organisms (for instance, barnacles) living between tide marks, on the foreshore are characteristic. This is the *Littoral Life-zone*, but below tide marks great seaweeds (*Algae*) flourish on suitable bottoms, and fishes, crabs, starfishes, etc., are abundant: this region immediately out from the littoral region is called the *Laminarian Zone*. Beyond the Laminarian region and out to several hundreds of fathoms of depth is the *Coralline Zone*, also with a fairly distinct fauna. Beyond the Coralline Zone is the *Deep Sea Region*, deepening down to the *Abyssal* one at over 3000 fathoms. The limits of these zones and region are not very precise and there are deviations due to local conditions. The reader may find data to qualify the above classification by personal knowledge of rocky, sandy, etc., foreshores, and also by observations of the catches made by fishing vessels. Admiralty charts should be consulted.

Geographical and regional faunas and floras. The zoning, as above, is only a very general scheme. There are geographical provinces of life, so that, on the whole, different faunas and floras inhabit widely separated oceans. (Curiously, the similarity of many forms of life in Arctic and Antarctic seas has always been maintained by some biologists). Even small, local sea-areas, North Sea, English Channel and Irish Sea, for instances, tend each to exhibit rather different proportions of marine species,

and there may be some species entirely exclusive to nearly situated marine regions.

Abyssal Life. All beyond the continental shelf may be called the deep sea faunistic region. In depths over about 2,000 fathoms we may call the life *abyssal.* There are no plant organisms on the sea bottom beyond the continental shelf.

When the deep sea and abyssal regions were first well explored (by the *Challenger*) it was found that there were no very archaic forms there—as had been expected. All the *groups* of deep sea and abyssal animals also inhabit the shallower regions. Marine animal life evolved in shallow water and gradually spread into the deeps and only rather unimportant adaptations of habits and structure have been made in response to the peculiar conditions in the abysses—enormous pressure (one ton per sq. inch per 1,000 fathoms) ; cold (about zero, Centigrade) ; complete darkness ; monotony ; nearly motionless water.

Abyssal animals tend to be coloured in monotones ; fishes have either unusually big eyes, or unusually small eyes, or are blind and their skeletons are fragile ; their flesh soft and spongy ; their heads and mouths big ; their trunks and tails attenuated. Many animals are phosphorescent. All animals feed on the bottom ooze, but many are markedly predatory.

The deep sea oozes are partially organic in material. Bodies of planktonic animals and plants that fall to the bottom do not rapidly decompose, because of the low temperature. Therefore this ooze (which is almost entirely formed of the remains of planktonic organisms) is edible.

The Sea-Serpent. Most of the recorded sea-serpents are mare's nests ! But the accounts of some are very circumstantial, and it cannot be dogmatically denied that some very large and unknown animals exist in the ocean and only make very rare appearances. Very large animals can only be " going concerns " in water ; under unknown conditions (as the Mesozoic Reptiles), or in conditions of decreased gravitational intensity (Mr. Wells' Mooncalves !) The known, large marine animals are the whales (up to 80 feet) and the giant squids, or Calamaries (up to 70 feet). Such animals living in the ocean abysses could not be caught by any fishing gear that is practicable and they could not generally rise into water near the surface.

It is possible, and it has been argued by some zoologists, that the sea-serpent accounts that are most creditable refer to some great marine mammals, or perhaps amphibians. But usually the accounts given by seamen relate to the giant calamaries.

Density of Life in the Oceans. By density of life in the oceans and tributary seas we mean (1) numbers of individuals per unit volume of water, or unit area of surface, or bottom, and (2) numbers of organisms coming into existence per unit of time and area (or volume). *Variety of Life* means numbers of species per unit region or volume.

Now these general statements may suffice:

(1) There is greater variety of life (and particularly animal life) in tropical and subtropical than in temperate and polar seas;

(2) Animal and plant life is conspicuously more dense in polar and temperate seas than in tropical and subtropical ones; this applies particularly to planktonic plant life (mainly diatoms). Evidences are (*a*) the great fisheries of the N. temperate seas—even on the Siberian continental shelf fish are now known to be abundant. There are rich fisheries (exploited by British vessels) on the coasts of Iceland, in the fiords of Greenland (in Davis Straits) and in the Barents Sea; (*b*) The rich plankton of all polar and subpolar waters that have been sampled; (*c*) the polar regional whale fisheries; (*c*) the Antarctic penguin rookeries.

(3) The most sparse plankton catches made in the oceans come from the Sargasso Sea.

(4) The greatest density of life (crustacea, molluscs, zoophytes, algae, fishes, etc.) has been observed on the shallow water sea bottom just outside the littoral zone. It is here, and on the foreshore that organic production is most dense.

[" Producers " are those organisms, almost entirely plants, that can synthesise organic materials from CO_2, HO_2, nitrates, nitrites, ammonia and other inorganic materials. " Consumers " cannot do this. All animals are consumers and most subsist on the living or dead tissues of other animals and plants].

(5) *Why differences of density of life exist.* Thus the density of animal life is determined by the density of plant life. Then the density of plant life is ruled by the proportions in which inorganic nitrogen compounds (say " nitrate " for short) exist in solution in sea water. The amount of this indispensable substance in a litre of sea water may be only one, or a fraction of a milligram.

Certain forms of bacteria destroy nitrate, reducing it to elementary nitrogen. These denitrifying bacteria function more vigorously in higher, than in lower temperatures, and therefore they destroy the indispensable plant food-materials more quickly in the tropical waters than elsewhere. Therefore plant life, and consequently animal life, are least abundant there.

(See further, "Science of the Sea," Challenger Society, 1928).

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